USES OF AMERICAN WATER-WILLOW (*Justicia americana*) BY RESERVOIR FISHES AND INVERTEBRATES IN LAKE CONROE, TEXAS

A Thesis

by

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ABSTRACT

Water-willow (*Justicia americana*) is popular in fish habitat improvement projects because of its ease of establishment and relative resistance to herbivory by grass carp (*Ctenopharyngodon idella*). However, the response by the lentic fish community to water-willow establishment has not been well documented. This study uses 9.32m^2 plots of water-willow established by Texas Parks and Wildlife Department in Lake Conroe, Montgomery County, Texas. Three replicates were randomly selected for each category of plant patch diameter within the plot (bare substrate, small, medium, and large) in each of four consecutive seasons. Plots were block netted then electrofished exhaustively to capture fish inside the block net. A 0.5-m diameter plankton net was used to simultaneously collect representative samples for macroinvertebrates in the water column and on plant stems and to calculate patch stem density. A 3.8-liter benthic sediment sample was collected where the plant stems were removed. Macroinvertebrates and fish were identified to the lowest practical taxon to determine assemblage structure. Fish were identified to species, weighed to the nearest gram, and total length was measured to the nearest mm and stomach contents were examined. Fish size composition, relative weight (Wr), and stomach contents were compared for each species across water-willow stand categories and season. Results show that biodiversity and total abundances of both fish and macroinvertebrates within water-willow sites was greater than in un-vegetated control

sites. Water-willow patch size and stem density had little impact on sport fish Wr and length frequency distributions.

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CHAPTER I

INTRODUCTION

The native range of the perennial macrophyte American Water-willow (*Justicia americana*), herein referred to as water-willow, extends from southern Texas into northern Canada and from Kansas to the eastern coast of the United States and inhabits shallow riffles and stream banks (USDA and NRCS, 2015; Penfound, 1940). It is classified as a dicotyledon, often grows in circular stands, and has perennial rhizomes (Fritz et al., 2003). After fall senescence the rhizomatous network remains during the cold winter months (Keating and Simmons, 2014), allowing rapid re-growth to occur in the spring (Twilley et al., 1985).

Much work has been done on lotic growth of water-willow. It influences stream biodiversity by increasing sediment stability via growth of roots and rhizomes that provide attachment points for various macroinvertebrate taxa such as gastropods and filter feeding caddisfly larvae (Fritz et al., 2004). Keating and Simmons (2014) demonstrated that water-willow not only contributes to the naturally occurring amount of locally available carbon, and within the whole stream system. In contrast, no documentation is available regarding growth and function of water-willow in lentic systems and effects on macroinvertebrate and fish assemblage structure and function. Its presence in lentic systems is not well documented and should properly be assessed because lentic water-willow can occupy a range of water depths and thus has potential as a species for efficient habitat restoration and management.

Characteristics of water-willow that support its use as an integral part of habitat management projects in reservoirs include: its hardy nature and tolerance to desiccation (Strakosh et al., 2005), ease of establishment and resistance to aquatic animal herbivory. As a case for its hardy nature, water-willow can allocate water via its rhizomes to daughter ramets, allowing the plant to survive during drought and fluctuating water levels (Touchette et al., 2012); it also can persist in water bodies inhabited by nonnative Grass Carp (*Ctenopharyngodon idella*) that have been stocked to consume excessive and invasive types of vegetation.

Structural complexity of habitats can strongly influence availability of resources within an aquatic system (Rennie et al., 2005). For example, macroinvertebrate densities increase as microhabitats become more complex, and macroinvertebrate abundance is positively correlated with macrophyte biomass (Rennie et al., 2005; Savino et al., 1992; Spotte, 2007; Beckett et al., 1992). Macrophytes, including water-willow, also provide a structure for aquatic larvae to climb to the water's surface to complete their lifecycle to adulthood (Cowx and Welcomme 1998). Habitat manipulations show that complex physical structures provide refugia for organisms within the water column, resulting in greater local abundance and diversity of zooplankton, macroinvertebrates, and fishes (Strakosh et al., 2006). In fact, many fish species show a preference for habitat with more complex structure (Killgore et al., 1993). Alternatively, when habitat complexity increases above species-specific thresholds, it can negatively affect foraging efficiency of predatory fishes; Largemouth bass (*Micropterus salmoides*) were unable to successfully forage on Bluegill sunfish (*Lepomis macrochirus*) when vegetation densities exceeded 99 stems/m^2 (Savino et al., 1992). However, Bluegill showed no differences in growth among various vegetation densities despite a tendency of decreased foraging efficiency with increased vegetation density (Savino et al., 1992; Beckett et al., 1992). Vegetated plots in reservoirs could increase survival of juvenile fishes of both game and non-game species, by reducing the efficiency of piscivorous predators, thus increasing the probability that juveniles utilizing vegetation will recruit to adulthood. For example, age-0 Largemouth bass tend to occur in greater abundances in water-willow stands as compared to non-vegetated areas (Strakosh et al., 2009). Increased structure provided by water-willow also reduces mortality of juvenile largemouth bass (Stahr and Shoup, 2015). Macrophytes within the littoral zone increase habitat complexity and increase biodiversity by balancing competition and predation among community taxa (Manatunge et al., 2005; Rennie et al., 2005). More specifically, water-willow is associated with increased abundance and diversity of macroinvertebrates and fishes (Strakosh, 2006).

Personnel from the Texas Parks and Wildlife Department (TPWD) Inland Fisheries office in Snook, Texas planted Water-willow stands in the Caney Creek arm of Lake Conroe, an impoundment of the upper San Jacinto River, near Conroe Texas in the summer drought of 2011 (USGS, 2014; National Integrated Drought Information System, 2014) to reintroduce vegetation in the presence of nonnative, herbivorous, triploid Grass Carp. The stands have persisted and currently are growing in water depths averaging 1.2 m (range 1 to 1.3 m). These stands also demonstrate a distinct growth form compared to plants in streams. Because water-willow in reservoirs has not been studied, and its influence on other components of lentic communities has not been reported in the literature, this study will also focus on its ecological value to reservoirs, using Lake Conroe as a study system.

An increasingly popular method to trace trophic pathways among components of a food web is to assess their stable isotope composition (Fry, 2006). Stable isotope analysis applied in mangrove ecosystems showed sedimentary material as the food source of macrozoobenthos (Wardiatno et al.; 2015). Malek et al. (2016) utilized this technique to study fishes and invertebrates in a coastal system. I will apply this technique in Lake Conroe to evaluate carbon and nitrogen signatures in plants, macroinvertebrates and fishes in order to determine if water-willow directly or indirectly provides food resources for higher trophic levels, or else contributes only to physical habitat complexity.

Primary Objectives

The primary objectives of this study are:

1. Evaluate the ecological value of water-willow across a range of patch diameters and stem densities in the littoral zone of the Caney Creek arm of Lake Conroe, TX during four consecutive seasons (Summer 2015, Fall 2015, Winter 2016, Spring 2016) by assessing
    a. fish diversity, assemblage composition, size structure and individual body condition (Wr) of sport fishes
    b. macroinvertebrate diversity and assemblage composition
2. Describe the influence of water-willow on the trophic pathways within the littoral zone of Lake Conroe reservoir in TX using stable isotope signatures for carbon and nitrogen.

CHAPTER II

METHODS

Study Site

The Caney Creek arm of Lake Conroe on the San Jacinto River, is located in the upper West half of the lake, which is bordered by the Sam Houston National Forest (Figure 1). Exotic plant species observed in the lake are primarily water hyacinth (*Eichhornia crassipes*), common salvinia (*Salvinia minima*), giant salvinia (*Salvinia molesta*) and hydrilla (*Hydrilla verticillata*). Recent grass carp stockings began in 2006 to control hydrilla. However, native vegetation cover was reduced from 1000 acres to 150 acres after these stockings (Webb, Best and Gore, 2013).

The shoreline soils are primarily clay. Individual stands of Water-willow are located from 6m to 16m from shore at a mean depth of 1.2 m, with only slight variation as water is held or released by the dam. Most water-willow stands are located within the Caney Creek arm where they were planted under the direction of TPWD in 2012. However, water-willow can be found in other areas of the lake.

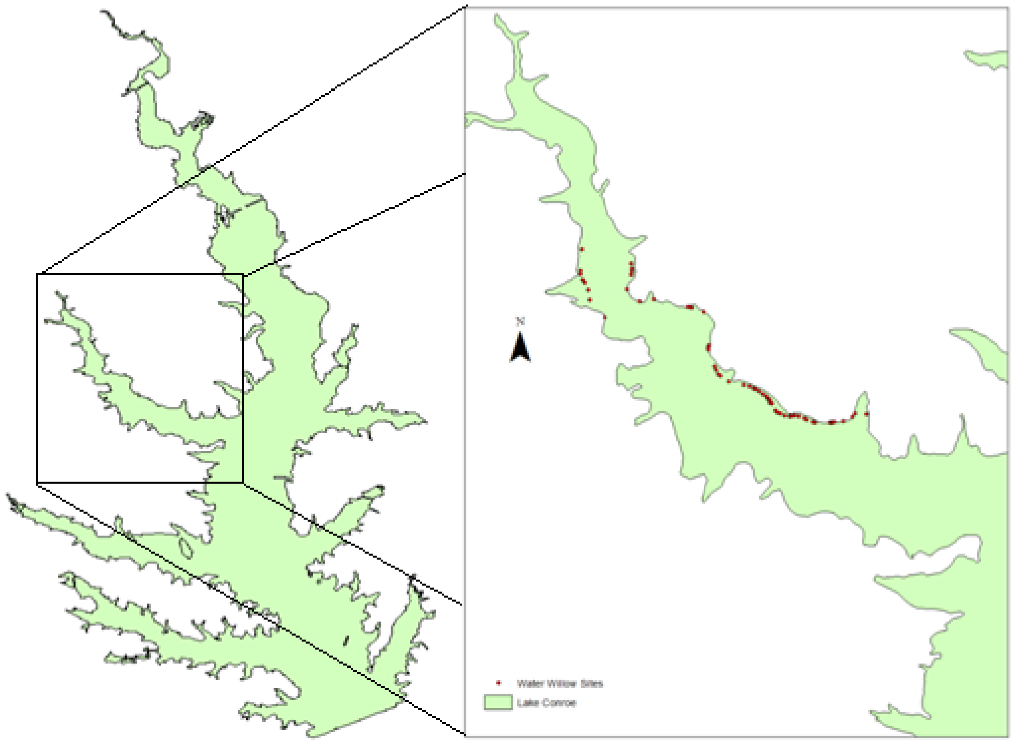

Figure 1 A. Lake Conroe, Conroe Texas. B. All potential water-willow sites within the Caney Creek arm of Lake Conroe, Conroe Texas.

Field Methods

A survey of all water-willow stands within the Caney Creek arm was conducted in each of four consecutive seasons: summer, fall, winter and spring. Stands of aquatic vegetation were categorized into three groups based on surface area diameter: bare substrate (containing no vegetation), small (1.0-2.0 meters), medium (2.1-3.5 meters), and large (3.6-5.5 meters). Thirty potential sites for sampling bare substrate were identified as those at least 15.24 meters apart. In the summer of 2015, locations of vegetated stands and their diameter were recorded into waypoints using a global positioning system (GPS) in the field. Three stands were randomly selected from each diameter category in each season. All field samples were labeled to correspond to the site location and date of collection, preserved in ice water, in ice chests, without chemical preservatives and then taken to TPWD office in Snook TX. Fishes were placed in a freezer (-4˚ C) while stems, soil, and water column samples are processed to collect data.

Sites were sampled by encircling an area (18.3 m circumference) with a seine (1.8 tall, 0.6 cm mesh size) and using metal poles temporarily driven into the sediment to support the net during sampling. Poles are then removed for use at the next site. Nylon clips were used to securely close the ends of the net in order to retain fishes. Exhaustive electrofishing of the enclosed patch area was conducted using a boat mounted electrofishing unit powered by a 5000-w generator and collected using a 0.6-cm mesh dip net (Non-square net, anterior length of 43 cm, posterior length of 34 cm and net depth of 55 cm). Electrofishing continued for a minimum of three minutes and end when fish are no longer collected within the sampling field during an additional two minutes. Fishes were transferred to a plastic bag, labeled, and placed in ice water during the remaining field procedures.

Next, macroinvertebrates and water-willow stems were simultaneously collected from one randomly selected representative area designated on a gridded map of the vegetated portion of the stand, where each grid represents a 0.5x0.5m area (Figure 2). A 0.5m diameter, 500-µm mesh plankton net was used to enclose water-willow stems, which were then cut off at the level of the sediment. The cut plant stems were transferred from the plankton net to a labeled plastic bag and stored in ice water. Any macroinvertebrates that remained in the plankton net were washed down into the cod end, transferred to a Nalgene bottle, labeled, and stored in ice water.

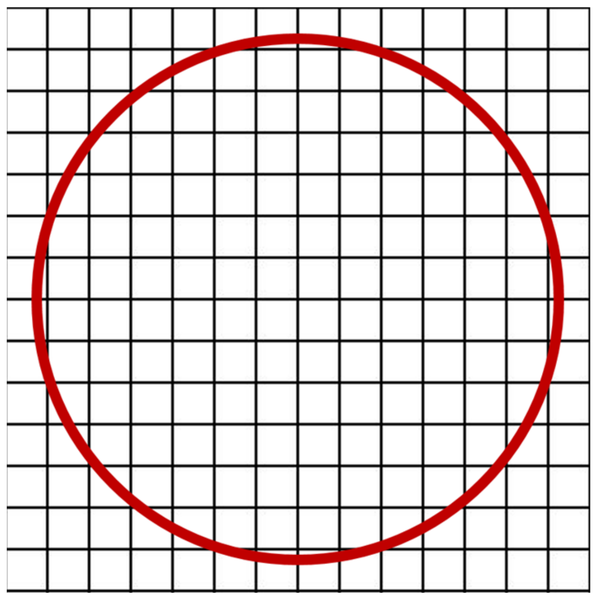

Figure 2 Vegetation sampling grid

Finally, using a calibrated bucket, 3.8 liters of soil were excavated where water-willow stems had been removed. Samples were transferred to a labeled plastic bag and stored in ice water. If a randomly selected sub-area within the stand did not fall within a vegetated area a new location for the sub-sample was randomly re-selected until a vegetated sub-area was identified. Following sample collection an YSI 556 MPS unit measured water parameters temperature (˚C), conductivity (µS), salinity (ppt), pH and dissolved oxygen (DO, mg/L). These parameters were recorded and correspond to the collection site location. The YSI probe was placed either adjacent to the water-willow stands on the shoreline side, or for bare substrate sites on the inside of the net on the shoreline side.

Laboratory Methods

Stems of water-willow were counted and stem density was calculated and recorded as stem count per 0.5-m diameter for each stand sampled. Macroinvertebrates (designated here as > 2 mm across the longest axis) were picked by hand from leaves and stems, combined, preserved in 70% ethyl alcohol and labeled as the vegetation sample. Macroinvertebrates that were washed into the cod of the plankton net were picked, preserved in 70% ethyl alcohol and labeled as the water-column sample. Soil collected was sieved (420µm mesh) to separate macroinvertebrates from debris, sand, and other material. Macroinvertebrates sieved from the soil sample were placed in a separate bottle, preserved in 70% ethyl alcohol, and labeled with the collection site and date.

All individuals were quantified for macroinvertebrate samples containing fewer than 200 individuals. For samples that contained more than 200 individuals, the EPA Rapid bioassessment method of counting was applied as follows: The sample contents were mixed and evenly spread across a gridded pan and then all individuals from four randomly selected grids were identified and counted. If the four grids together contain more than 200 individuals, the contents of the four grids were combined and spread into a second, but identical-size gridded pan, and the same procedures applied to count individuals in four randomly selected grids (Barbour, 1999). These macroinvertebrates were identified using Merritt and Cummings (1996).

Fishes were removed from the freezer, thawed and identified to species using Thomas, Bonner and Whiteside (2007), and total length (mm), standard length (mm), and weight (g) were recorded. For the most common species, 30 individuals were measured and weighed and the remaining were counted with the 30 recorded individuals as total fish count data. For the 30 individuals of most common fish species, stomachs were dissected and contents were extracted to identify and count prey items, which were placed in labeled vials corresponding to the individual fish and its length, weight and species.

Statistical Analyses

Fish and Macroinvertebrate Assemblages

The Canonical Community Ordination version 5.0 statistical program (CANOCO, ter Braak and Smilauer 2002) was used to conduct multivariate statistical analyses. After screening analyses using DCA (Detrended Correspondence Analysis), CCA (Canonical Correspondence Analysis), PCA (Principal Component Analysis), and RDA (Redundancy Analysis), the RDA was chosen as the most optimal method (greatest amount of variation in dependent variables were explained by the explanatory information). Variation partitioning within the CANOCO 5.0 statistical program was used to evaluate fish and macroinvertebrate assemblages regarding explanatory value of categorical, seasonal and water parameter data. Variation partitioning was used to parse the variation in assemblage data explained by groups of explanatory variables and tested for significance ($P \leq 0.05$) using Monte Carlo simulations (Figure 3., Fish assemblage partition- Group A: Season, Group B: Stem Count and Stem Weight, Group C: Plot Size Category and Diameter; Invertebrate assemblage partition- Group A: Season and Water Column Location, Group B: Stem Count and Stem Weight, Group C: Plot Size Category and Diameter). Total individuals observed for each species were summed and species percentage make up was calculated. Fishes that make up <0.1% of the fishes observed will be deemed uncommon and therefore excluded from the analysis. A similar application will be used with macroinvertebrate counts where taxa representing <0.04% were deemed uncommon and excluded from analysis.

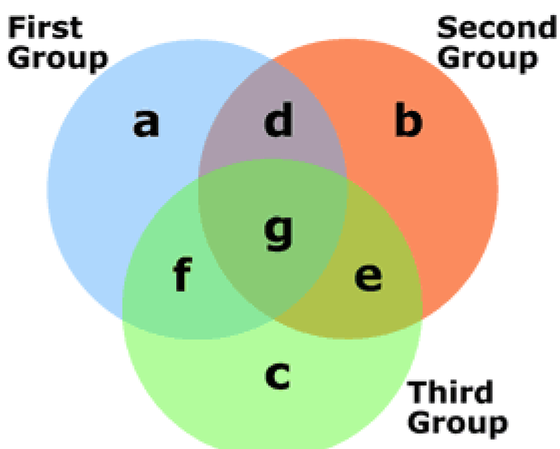

Figure 3 Venn diagram describing group comparisons under variation partitioning analyses of samples. A, B and C are the three defined groups, these groups are analyzed individually and then together as indicated A+B=D, B+C=E etc. The analyses also shows variation shared amongst all defined groups (A+B+C+D+E+F=G).

Fish Species Abundance and Length Frequency Distributions

Sport fish total abundance, mean weight (g) and mean total length (TL) mm were calculated across vegetation categories and sites. Fishes weighing <1 g were excluded from mean weight and TL calculation because a true weight value is unavailable. To test for effects of vegetation category on fish length distributions (1.0 cm intervals), total length (TL) of individual sport fishes were recorded. Largemouth bass, bluegill and channel catfish were categorized into stock, quality, preferred, memorable or trophy Gabelhouse sizes (Anderson and Neumann, 1996, Gabelhouse, 1984). The statistical program SAS 9.4 (Statistical Analysis System) was used to run a K/S test to asses' effects of season, water willow stand size category and stem density on these length distributions.

Relative Weight Indices

Relative weight indices (Wr), based on 1cm size classes, were calculated to evaluate body condition (plumpness) of Largemouth Bass, Bluegill and Channel Catfish (Anderson and Neumann, 1996; Pope and Kruse, 2007), as compared to other fish of the same species and size. The statistical program SAS 9.4 was used to run an ANOVA to evaluate sport fish body condition across stand size categories and seasons, and to run an ANCOVA to evaluate sport fish body condition across stand size categories and stem densities.

Stomach Contents

Stomach contents were viewed under a dissecting microscope for individual counts of prey items and identification to the lowest practical taxon using Merritt and Cummins (1996). Stomach contents of cyprinids were identified; since a limited number of individuals held prey items, ANOVA and post-hoc Tukey tests were used to test for effects of stand size category and season on the number of individuals with contents. These analyses utilized prey presence and absence among individuals. Stomach content data were displayed graphically using the frequency of occurrence formula ($O_i=J_i/P$),

O_i=frequency of occurrence of the prey item in the sample

J_i=number of fish within the same species that consumed the prey item

i=the prey item

P=Number of conspecific fish that contained food

and prey specific abundance based on a formula modified by Amundsen et al. (1996) of Costello's (1990) model (Figure 4.). ($P_i=[\Sigma S_i/\Sigma S_{ti}]100$)

P_i=prey specific abundance

i=the prey item

S_i=abundance of prey i in stomach of individual fish

S_{ti}=total abundance of all prey in predators that contain prey i

A graphical combination of these displays allows for analysis of feeding strategies among fish in the study, importance of prey type in observed samples and diet variability amongst individuals (Figure 5).

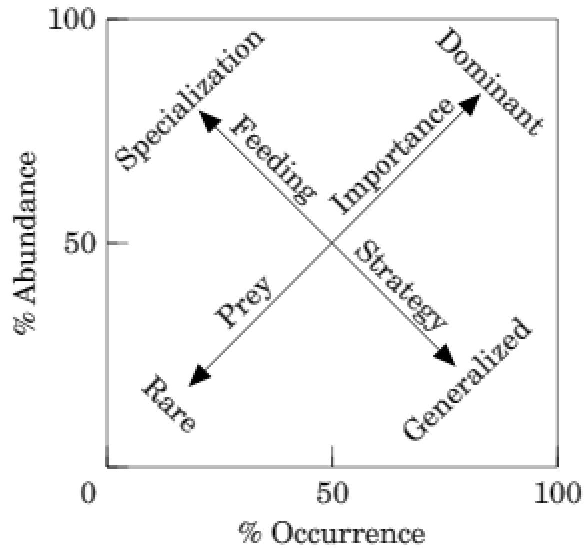

Figure 4 Costello's (1990) diagram describing his model.

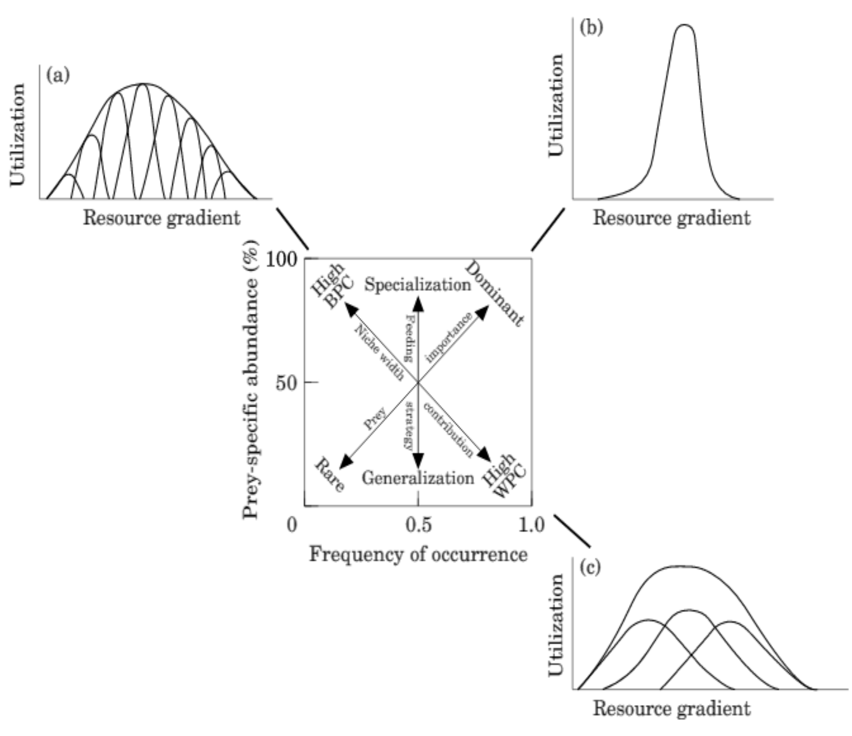

Figure 5 Description to allow interpretation of stomach contents (Amundsen et al, 1996).

Methods for Stable Isotope Analysis

All isotope collections occurred in summer 2016, when productivity and diversity is likely to be highest. Representative samples of plankton, fishes, macroinvertebrates and vegetation were collected from water-willow stands within the Caney Creek arm of Lake Conroe, Conroe Texas. Fishes were collected via a boat mounted electrofishing unit powered by a 5000-w generator and 0.6-cm mesh dip net. Fishes for isotopic analysis were only collected from water-willow stands to evaluate, specifically, water-willow effects on isotopic signatures. Water-willow stems and macroinvertebrates were collected utilizing a 0.5m diameter, 500-µm mesh plankton net. Algae and macroinvertebrates were removed from water-willow stems via wiping with paper towels, followed by rinsing to remove fibers left by paper towels. Macroinvertebrates were collected from the stems and water column during stem collection. These individuals were identified and separated to their respective taxonomic groups (Odonata, Chironomidae and Trichoptera) and pooled across water and stem locations to create homogenized samples. A separate water sample, using a 19-Liter bucket, was collected for plankton in order to reach a minimum 20 mg dry weight for isotopic analysis. Periphyton was scraped gently from the surface of water willow-stems to produce 4 mg of dry weight.

Plankton samples were held in an ice water bath for a maximum of 24 hours until processed. Samples of fishes, macroinvertebrates and vegetation were kept at - 4˚ C before processing for isotopic analysis. Plankton from water samples (20 liters) was filtered using Fisher brand borosilicate glass fiber, 1.5-micro mesh using a Gast Model 0211 vacuum pump. Fish muscular tissue was dissected from the dorsal region of the body for larger fishes (Bodin et al., 2007), whereas for smaller fishes, the whole body of fishes with the head removed was used. Cleaned water-willow stems with intact leaves were used for water-willow tissue (Xu et al., 2015) and whole individuals were used for macroinvertebrate tissues.

Fishes selected for isotopic analysis included adult and juvenile Largemouth bass, Bluegill, Gizzard shad (*Dorosoma cepedianum*), Threadfin shad (*Dorosoma petenense*), Weed shiner (*Notropus texanus*) and Bigscale Logperch (*Percina macrolepida*), due to their high prevalence in water-willow stands. Juvenile bass is defined as those restricted to total length under 152mm (Binder et al., 2015; Stahr and Shoup, 2015; Ameilda et al., 2012). Due to their smaller body length, both Threadfin shad and Weed shiner were processed by removing the head and keeping all the remaining body for analysis. Ten individuals per fish species were sampled. Macroinvertebrate taxa sampled were Odonata, Chironomidae and Trichoptera.

All isotopic samples were dried at 60 C° for 48 hours, then, ground to a powder at the Texas A&M Stable Isotopes for Biosphere Science Laboratory using a Retesch Oscillating Mixer Mill (MM400). Microscales were used to weigh out 1.0 mg (±0.02 mg) of each macroinvertebrate and fish and to weigh out 20 mg and 4 mg samples of plankton and periphyton, respectively, for isotopic analysis according to Texas A&M Stable Isotopes for Biosphere Science Laboratory procedures (Fry, 2006). Plankton samples were ground along with their filters as the borosilicate glass fiber filters have no nitrogen or carbon signature. Samples were analyzed by the Texas A&M Stable Isotopes for Biosphere Science Laboratory.

CHAPTER III

RESULTS

Water Parameters

Differences were detected amongst season (P=0.002), season and stand size category combined (P=0.002) and amongst all variables combined (P=0.002, Table 1). Higher temperatures were observed for both spring and summer seasons and were negatively correlated with those in the winter season. Increased salinity levels (ppt) and DO (mg/L) were associated with the winter season. Increased pH levels were correlated with medium stands and conductivity did not correlate with a particular season or category (Figure 6).

Table 1. Water parameter fraction F and P-values of partitioned CCA analysis. A=Season, B= Category and C= Diameter. Other letters indicate variation shared among groups as in figure 3.

Tested Fraction	F	P
a+b+c+d+e+f+g	3.7	0.002
a	7.2	0.002
b	0.4	0.832
c	0.4	0.398
a+d	7.6	0.002
b+e	0.3	0.95
c+f	2.4	0.104

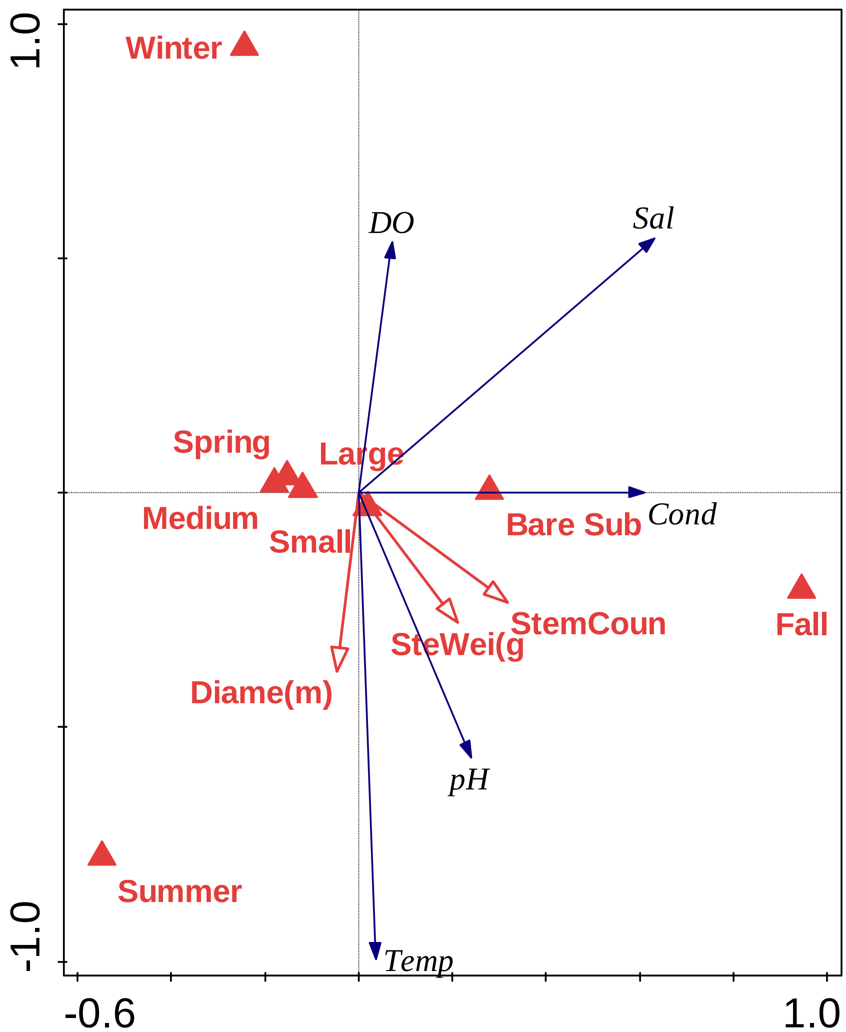

Figure 6 RDA analysis of water parameters on 1st and 2nd axes between season, category, diameter (m).

Fish Species Abundance and Length Frequency Distributions

Largemouth Bass

A total of 120 individuals were observed for largemouth bass across both season and size category. The highest number of collected largemouth bass individuals occurred in medium category sites (N=44) with the fewest in bare substrate category sites (N=7). Mean total length (TL) across all individuals was 15 cm and mean weight was 137 g (N=90). A length frequency distribution K/S test showed significant differences between bare substrate and small category (Table 2). The majority of individuals collected were less than 15 cm TL. Vegetated sites show similar distribution with individuals less than 13 cm forming a larger portion of the population. Large and medium category stands held an increased number of individuals greater than 19 cm (Figure 6).

Table 2. Largemouth bass length frequency distribution two-way K/S test D statistic and P-value between all category combinations.

Category Comparisons	**D Value**	**P-value**
Bare Substrate-Small	0.62	0.025
Bare Substrate-Medium	0.545	0.055
Bare Substrate-Large	0.555	0.216
Small-Medium	0.127	0.277
Small-Large	0.198	0.552
Medium-Large	0.108	0.973

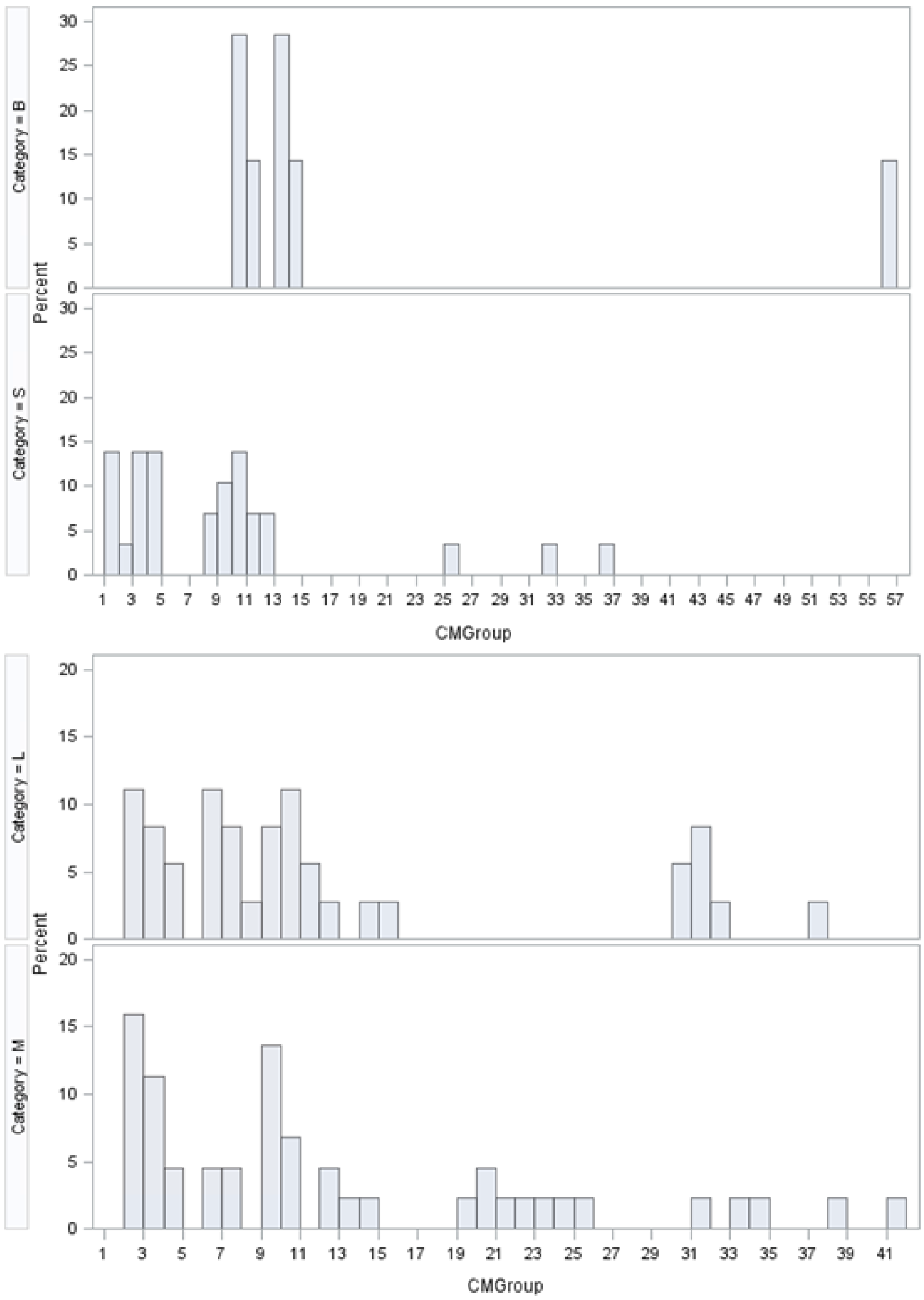

Figure 7 Largemouth bass centimeter group length frequency distribution as percentage values by category.

Bluegill Sunfish

A total of 1064 individual bluegill sunfish were observed across all samples. The highest counts were observed for the medium size category (N=477) and the lowest in the bare substrate category (N=1). Mean TL was 57 cm and mean weight was 17 g (N=813). A length frequency distribution K/S test showed significant difference between medium and large size categories (Table 3). Individuals less than five centimeters made up the largest portion of those collected. Larger individuals above five centimeters were collected and not uncommon but were not as prevalent. It should be noted the bare substrate category was excluded from the analysis because only one individual was collected throughout all seasons (Figure 8).

Table 3. Bluegill sunfish length frequency distribution two-way K/S test D statistic and P-value between all category combinations. Note: Bare substrate category has been ignored because only one individual was collected.

Category Comparisons	**D Value**	**P-value**
Small-Medium	0.114	0.34
Small-Large	0.122	0.266
Medium-Large	0.181	0.003

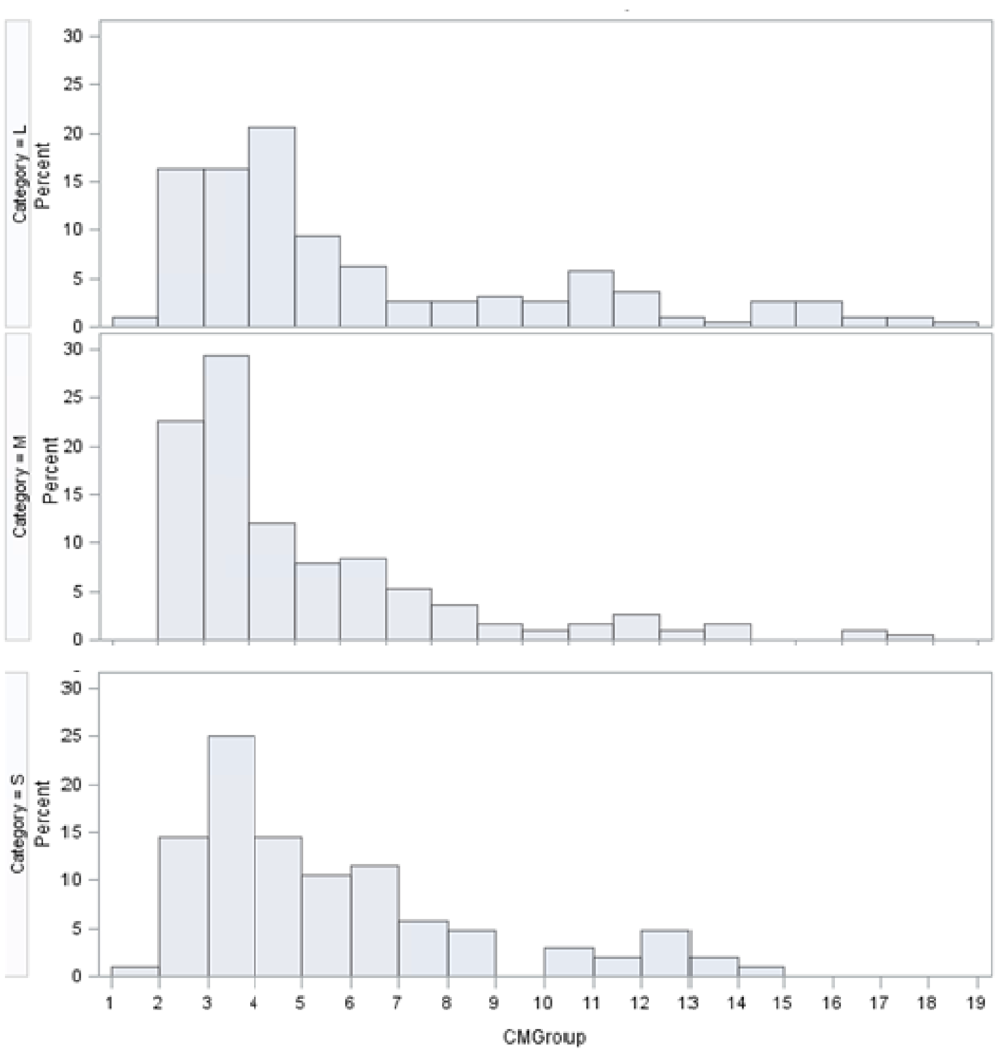

Figure 8 Bluegill sunfish centimeter group length frequency distribution as percentage values by category.

Stomach Contents

Across all observed fish species and individuals, *Chironomidae*, henceforth referred to as chironomids, were the most frequently observed prey item and when present made up the majority of total items consumed. This was observed across all vegetated categories. Other common prey items included *Amphipods*, fishes, *Hemiptera*, and *Trichoptera*. However, these prey items occurred less frequently and, when observed, often made up a small portion of total consumed items (<70%) compared to chironomids (>80%)

No fishes were observed in the bare substrate category site during winter sampling and therefore data regarding stomach contents is unavailable. Fishes observed (N=2) in the bare substrate category sites during the spring season did not consume chironomids. Other common prey items included *Amphipoda*, fishes, *Hemiptera* and *Trichoptera*. However, these prey items occurred less frequently and when observed often made up a small portion of total consumed items (<70%) compared to chironomids (>80%).

Largemouth Bass

Largemouth bass collected from the bare substrate category (N=6) utilized *Coleoptera*, *Amphipoda*, fishes and chironomids as prey. Fishes occurred the most often (O_i=0.833) and *Coleoptera* were the most abundant when consumed (P_i=60.975, Figure 9). Individuals collected from the small category (N=15) were *Hemiptera*, *Amphipoda*, *Odonata*, *Ephemeroptera*, fishes and chironomids. Fishes and chironomids were observed in all four categories. *Amphipoda* were the most common prey item for individuals from the small size category (O_i=0.133, P_i=68.571, Figure 10). Stomach contents from medium category sites (N=24) utilized *Hemiptera*, *Amphipoda*, *Odonata*, *Ephemeroptera*, *Trichoptera*, *Diptera*, fishes and chironomids as prey items. The most common taxa observed were fish (O_i=0.375, P_i=93.33, Figure 11). Other commonly used taxa within the medium category sites were chironomids (O_i=0.20, P_i=70.588) and *Hemiptera* (O_i=0.375, P_i=61.165). Lastly individuals from large category sites (N=17) utilized *Hemiptera*, *Amphipoda*, *Odonata*, *Diptera*, *Annelida Palaemonetes*, fishes and chironomids. The two most common taxa were fishes (O_i=0.47, P_i=76, Figure 12) and chironomids (O_i=0.411 P_i=56.521).

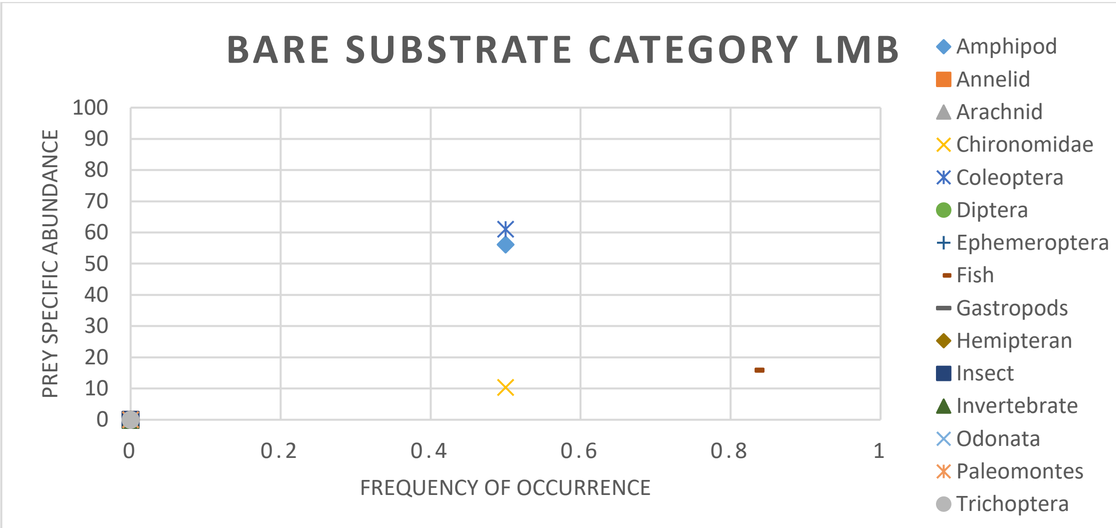

Figure 9 Frequency of occurrence plotted against prey specific abundance of largemouth bass stomach contents collected from bare substrate sites.

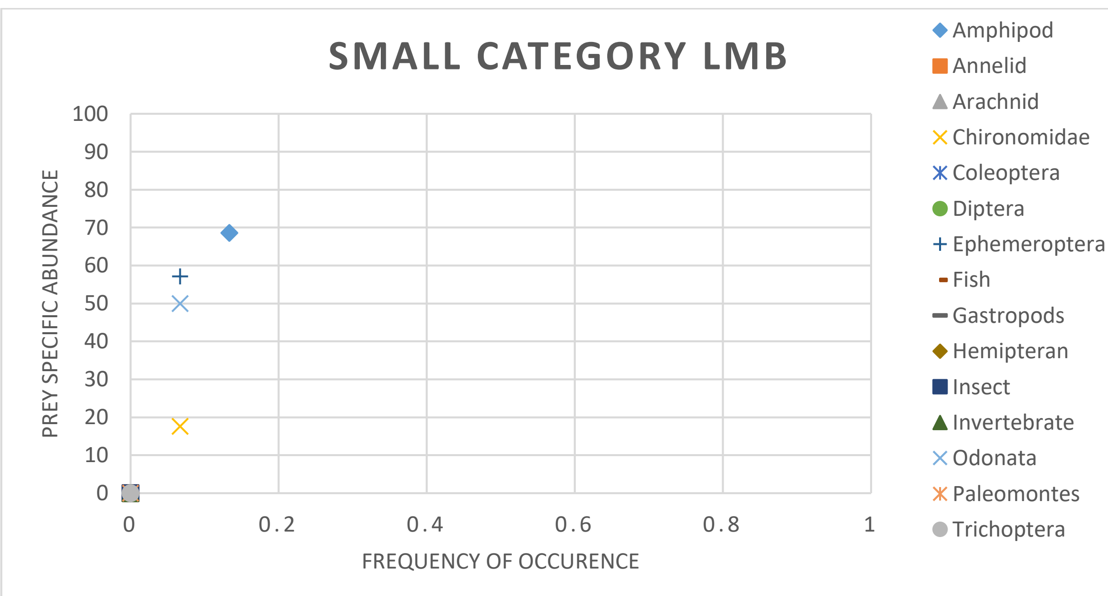

Figure 10 Frequency of occurrence plotted against prey specific abundance of largemouth bass stomach contents collected from small category sites.

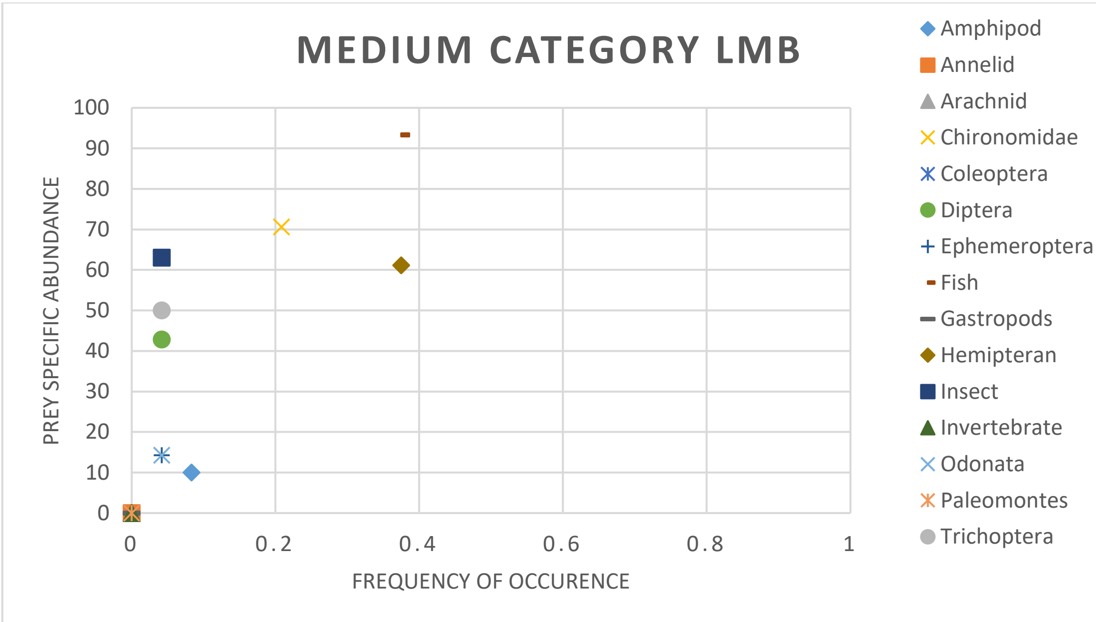

Figure 11 Frequency of occurrence plotted against prey specific abundance of largemouth bass stomach contents collected from medium category sites.

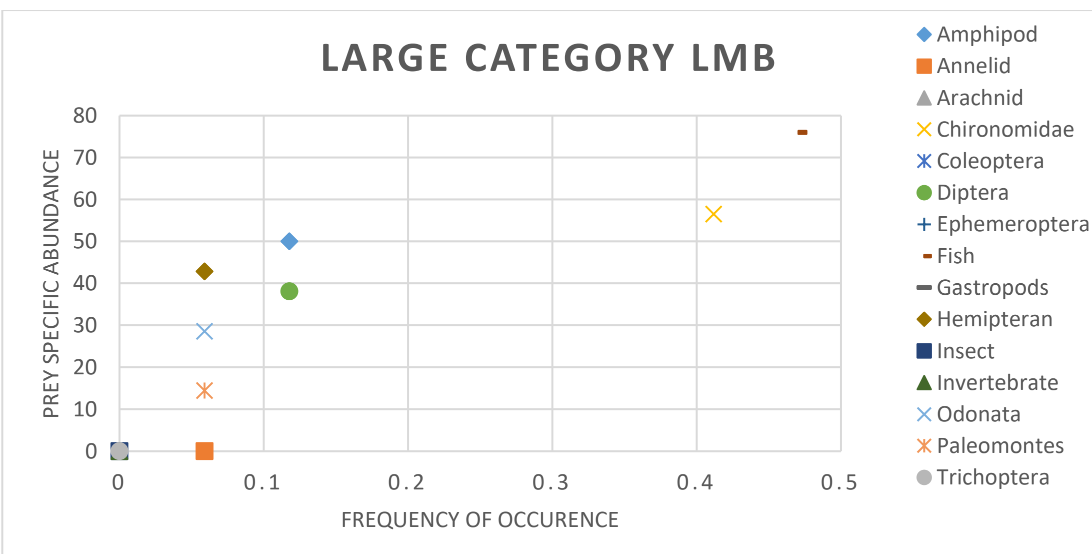

Figure 12 Frequency of occurrence plotted against prey specific abundance of largemouth bass stomach contents collected from large category sites.

Largemouth bass collected from the fall season consumed Amphipods, Coleopteran, Diptera, Ephemeroptera, Hemiptera, Odonata, Palaemonetes, prey fishes and chironomids, the most utilized prey item was Hemiptera (Oi=0.481, Pi=49.056). Chironomids had the highest calculated prey specific abundance (Oi=60.975, Figure 13). Individuals observed during the winter season (N=3) utilized Hemiptera, prey fishes and chironomids. All three prey items were equivalently dominant (Oi=0.333, Pi=100, Figure 14). Individuals collected in the spring season (N=18) utilized Amphipoda, Annelida, Hemiptera, Trichopters, prey fishes and chironomids as prey items. Hemiptera and chironomids were the most utilized prey item during the winter season (Oi=0.333, Pi=100, Figure 15). Individuals collected in the summer season (N=22) utilized Hemiptera, unidentifiable Insecta, prey fishes and chironomids. Prey fishes were the most utilized prey taxa (Oi=0.590, Pi=100) however all prey taxa frequency of occurrence values were 100 (Pi=100, Figure 16).

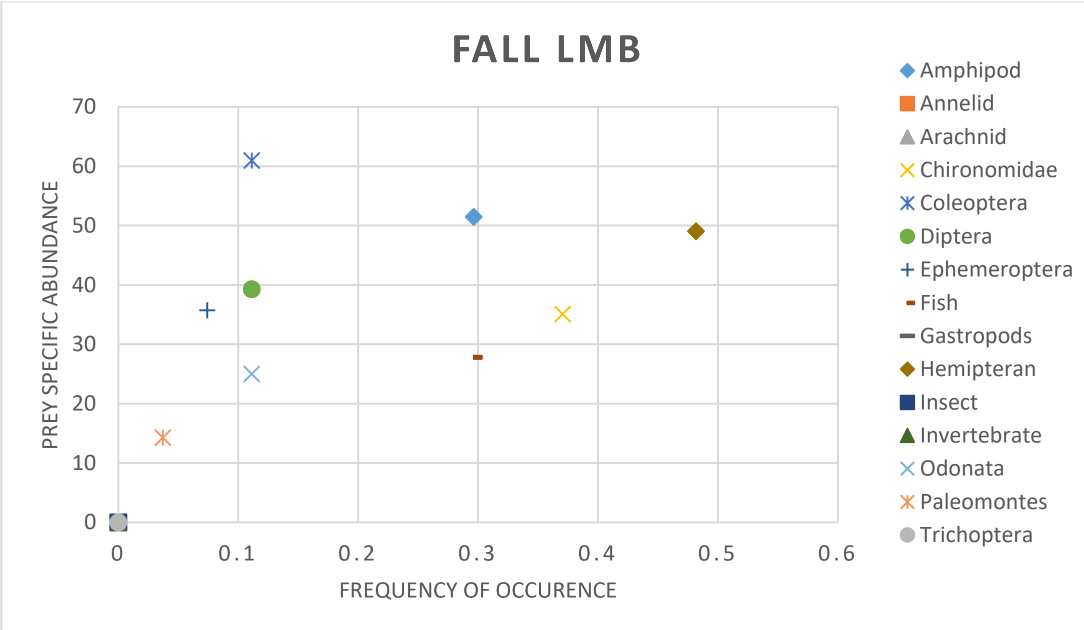

Figure 13 Frequency of occurrence plotted against prey specific abundance of largemouth bass stomach contents collected from fall season.

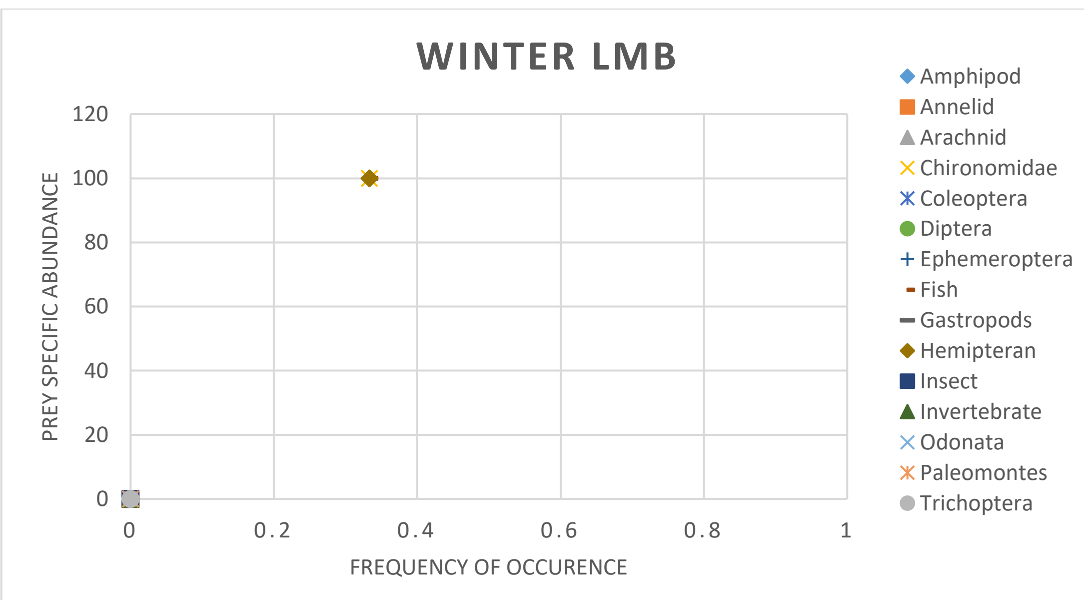

Figure 14 Frequency of occurrence plotted against prey specific abundance of largemouth bass stomach contents collected from winter season.

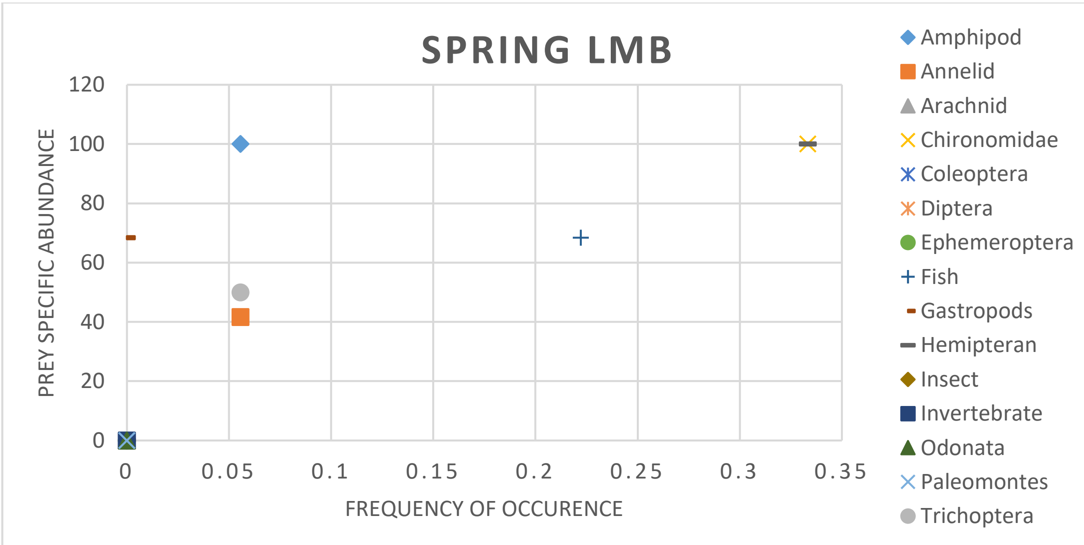

Figure 15 Frequency of occurrence plotted against prey specific abundance of largemouth bass stomach contents collected from spring season.

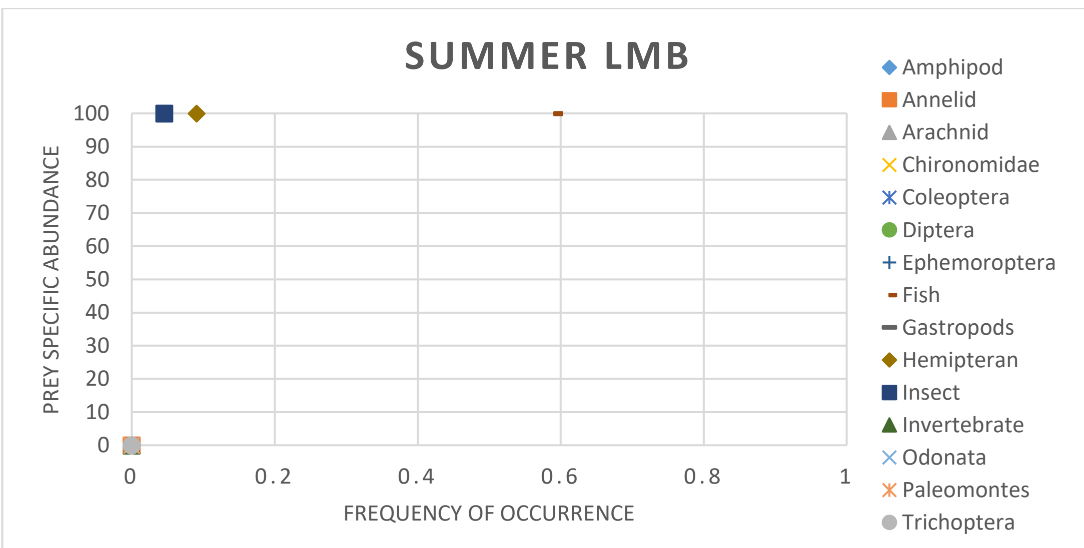

Figure 16 Frequency of occurrence plotted against prey specific abundance of largemouth bass stomach contents collected from summer season.

Bluegill Sunfish

Bluegill stomach contents showed little variation in prey taxa utilization across site categories. The single individual observed in the bare category site consumed one chironomid. Prey taxa consumed by individuals collected from the small category (N=88) were *Amphipoda*, *Coleoptera*, *Hemiptera*, *Odonata*, fishes and chironomids. The most common utilized prey from small category sites were chironomids (O_i=0.931, P_i=0.931, Figure 17). Prey taxa consumed by individuals from medium category stands (N=125) were *Amphipoda*, *Ceratopogonidae*, *Gastropoda*, *Hemiptera*, unidentifiable macroinvertebrate*, Odonata*, *Trichoptera*, fishes and chironomids. The most commonly utilized prey taxa were chironomids (O_i=0.424, P_i=0.88.053, Figure 18). Prey taxa consumed by individuals from the large size category (N=148) were *Amphipoda*, *Annelida*, *Ceratopogonidae*, *Diptera*, *Gastropoda*, *Hemiptera*, unidentifiable *Insecta*, *Odonata*, *Trichoptera*, fishes and chironomids. Again chironomids were the most commonly utilized prey taxa (O_i=0.945, P_i=0.85.541, Figure 19).

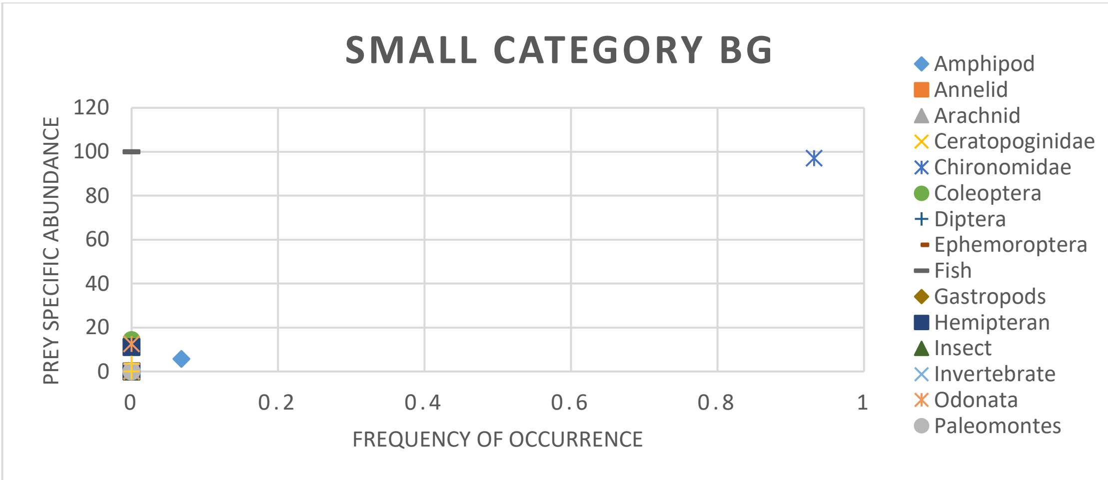

Figure 17 Frequency of occurrence plotted against prey specific abundance of bluegill sunfish stomach contents collected from small category sites.

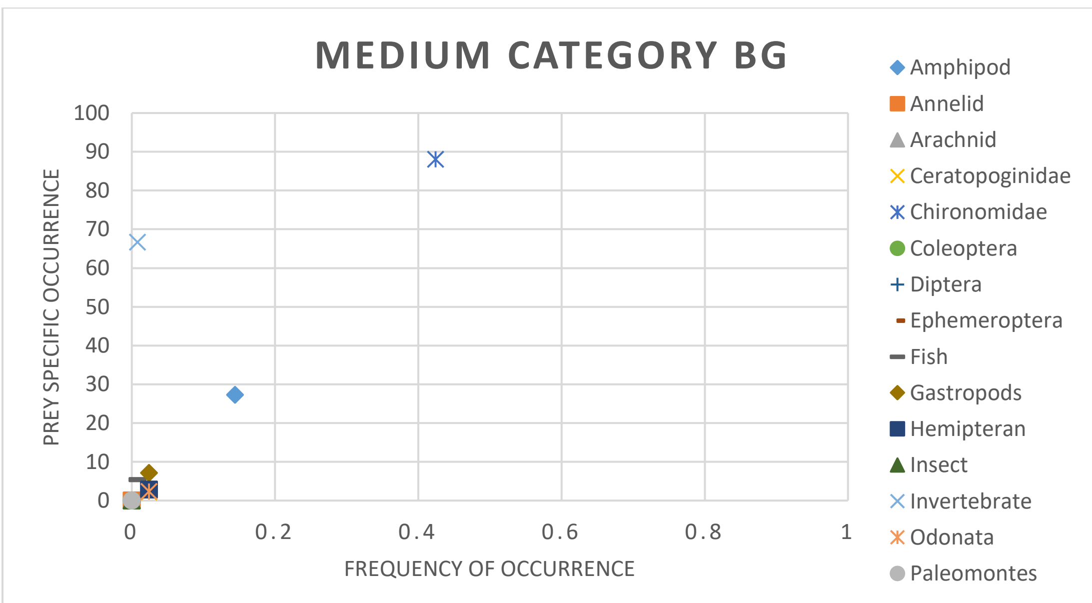

Figure 18 Frequency of occurrence plotted against prey specific abundance of bluegill sunfish stomach contents collected from medium category sites.

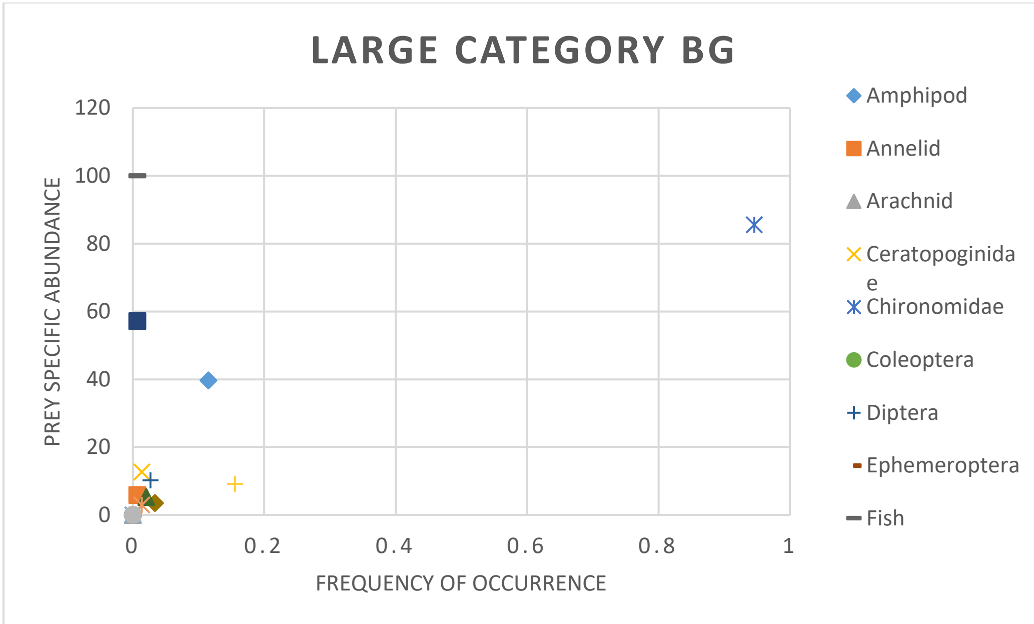

Figure 19 Frequency of occurrence plotted against prey specific abundance of bluegill sunfish stomach contents collected from large category sites.

Bluegill sunfish observed in the fall season (N=212) utilized *Amphipoda*, *Ceratopogonidae*, *Coleoptera*, *Diptera*, *Gastropoda*, *Hemiptera*, unidentifiable macroinvertebrate, *Odonata*, *Trichoptera*, prey fishes and chironomids as prey items. The most utilized prey in the fall season were chironomids (O_i=0.632, P_i=0.90.071, Figure 20). Individuals observed in the winter season (N=11) utilized *Gastropoda*, unidentifiable *Insecta*, *Trichoptera* and chironomids as prey. The most utilized prey were chironomids (O_i=1, P_i=58.598, Figure 21). Individuals observed in the spring season (N=75) utilized *Amphipoda*, *Diptera*, *Hemiptera*, unidentifiable *Insecta*, *Trichoptera* and chironomids as prey items. The most utilized prey were chironomids (O_i=0.933, P_i=72.35.). *Hemiptera* prey specific abundance value was the highest amongst prey taxa (O_i=0.013, P_i=100, Figure 22). Individuals observed in the summer season (N=66) utilized *Amphipoda*, *Annelida*, *Ceratopogonidae*, *Gastropoda*, *Hemiptera*, unidentifiable *Insecta*, *Trichoptera*, prey fishes and chironomids as prey items. The most utilized prey taxa were chironomids (O_i=0.924, P_i=95.273, Figure 23).

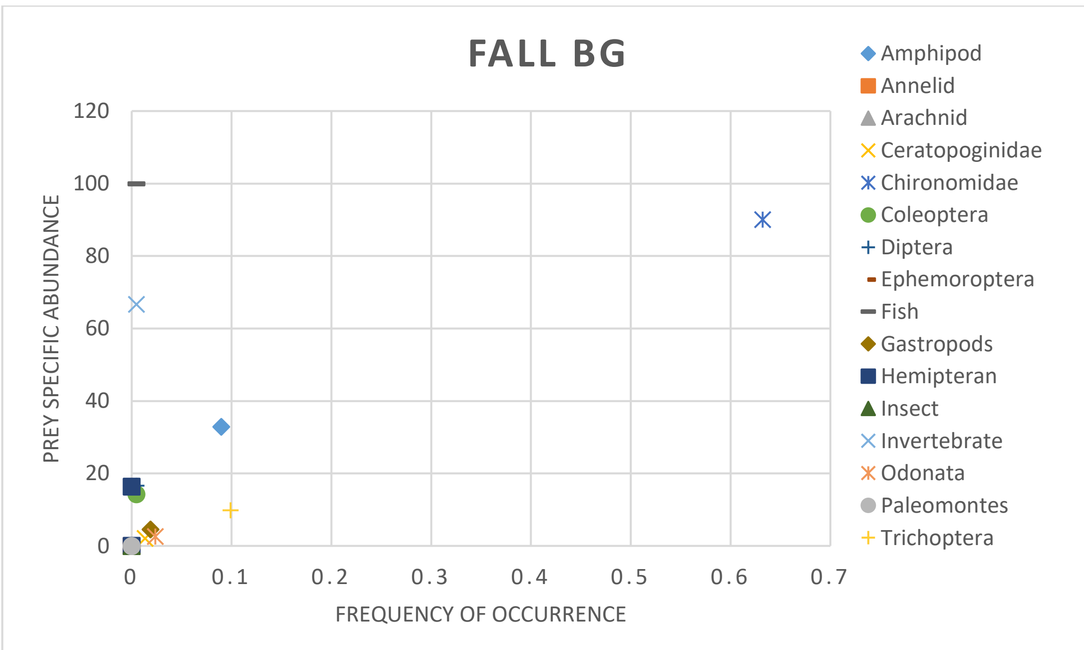

Figure 20 Frequency of occurrence plotted against prey specific abundance of bluegill sunfish stomach contents collected from fall season.

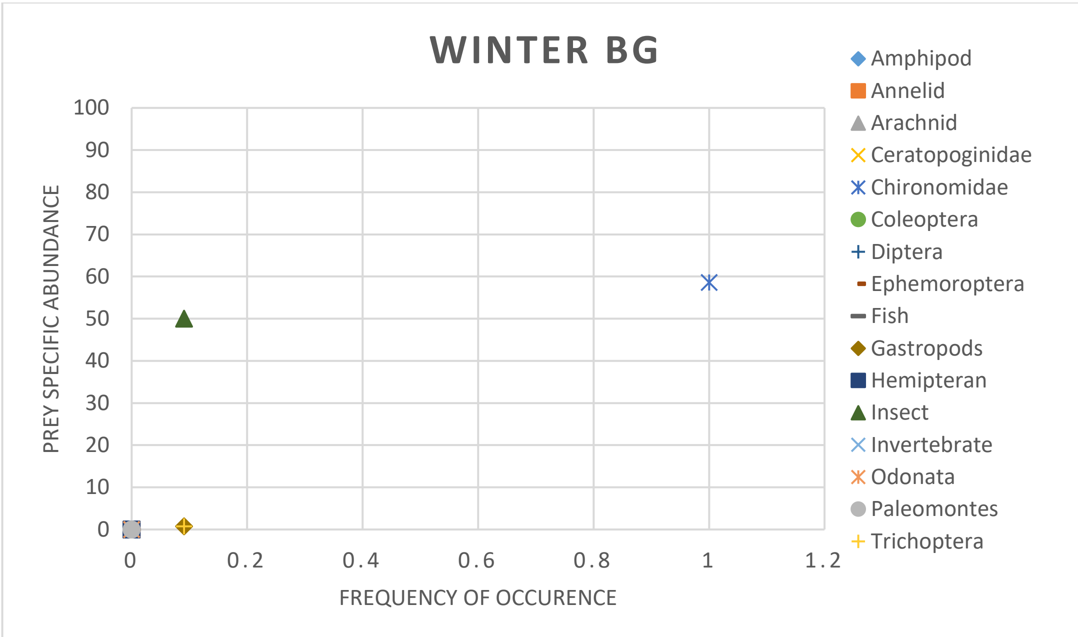

Figure 21 Frequency of occurrence plotted against prey specific abundance of bluegill sunfish stomach contents collected from winter season.

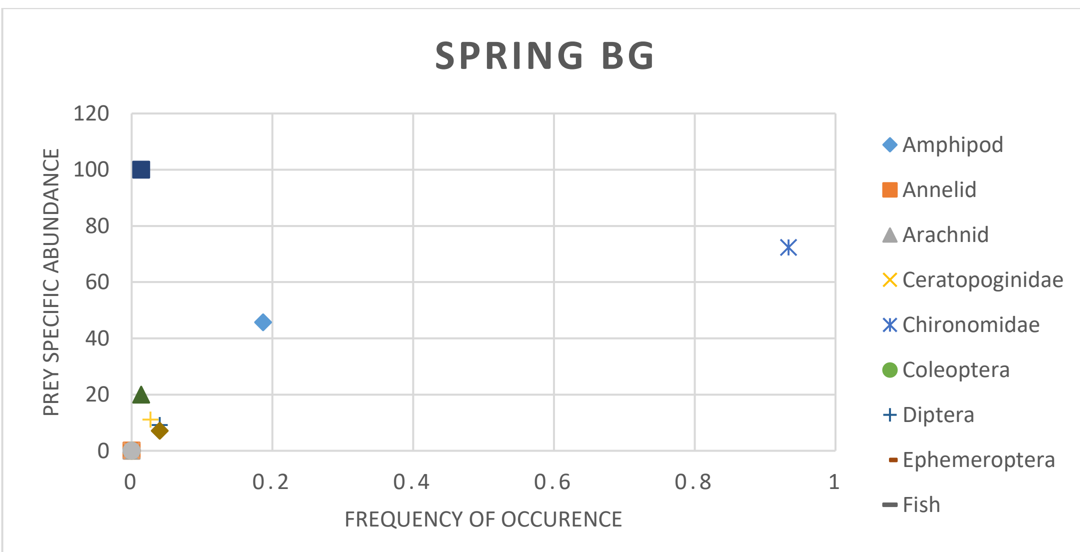

Figure 22 Frequency of occurrence plotted against prey specific abundance of bluegill sunfish stomach contents collected from spring season.

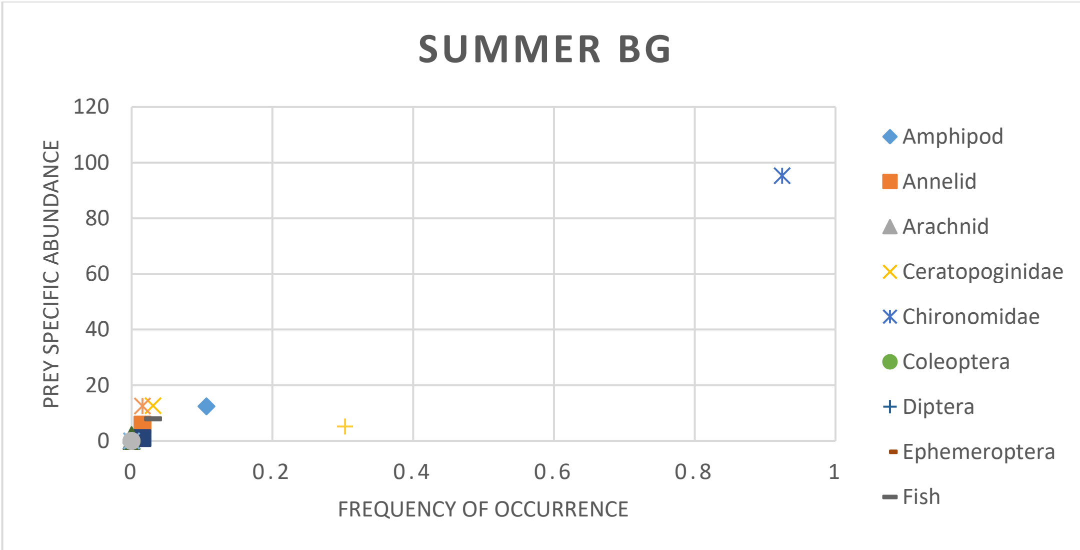

Figure 23 Frequency of occurrence plotted against prey specific abundance of bluegill sunfish stomach contents collected from summer season.

Cyprinidae

The minnows observed (N=788) for stomach contents included the weed shiner, bullhead minnow (*Pimephales vigilax*) and black-tail shiner (*Cyprinella* venusta). The majority of individuals with contents (N=264) held solely chironomids. Those that consumed other prey taxa (N=15) contained Annelida, *Crustacea*, *Diptera*, *Arachnid*, unidentifiable macroinvertebrate and *Trichoptera*. An ANOVA of all *Cyprinidea* species collected showed significant (P<0.05) differences due to season and category separately (Table 4). It should be noted it was not uncommon to observe individuals with no prey items. A Tukey test showed that comparisons between fall and summer and again between fall and winter were significant (P<0.05, Table 4). A Tukey test applied to the categorical gradient showed differences between large and small, and large and bare (P<0.05, Table 4). If contents were observed, often only the sclerotized head of a chironomid larvae were visible. Chironomids were the most utilized prey item across all samples (O_i=0.943, P_i=97.887, Figure 24). It should be noted one *Cyprinidae* individual collected from a bare substrate category site contained no prey.

Table 4. *Cyprinid* P-values of stomach contents present and difference between means of significant groups, as a result of a Tukey test.

Source	**P-value**
Season	0.004
Category	0.0041
Category and Season	0.4985
Tukey Results	
Season Comparison	**Difference in Mean Proportion of *Cyprinidae* with Contents**
Fall-Summer	21.875
Fall-Winter	43.62
Category Comparison	**Difference in Means Proportion of *Cyprinidae* with Contents**
Large-Small	21.636
Large-Bare	38.603
Medium-Small	18.606

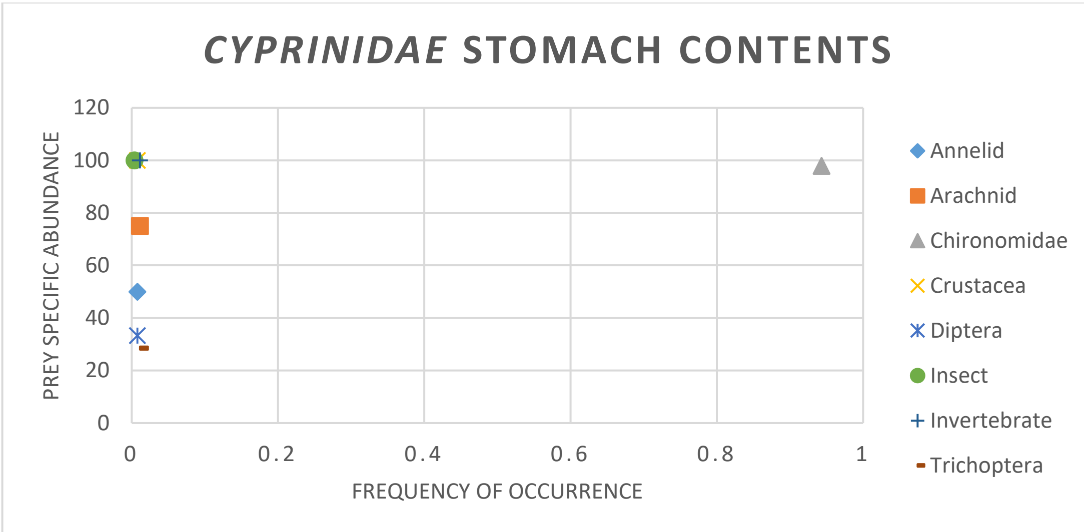

Figure 24 *Cyprinidae* stomach content across all samples.

Relative Weights (Wr)

Largemouth Bass

Relative weights (N=26) were calculated from all Largemouth bass individuals that met the minimum total lengths requirements (Anderson and Neumann, 1996). Largemouth bass of quality size (N=19) maintained Wr >90 across seasonal variations (Figure 25). Those of memorable (N=1), preferred (N=3) and stock (N=1) occurred in low abundance, however, Wr was >90 with the exception of a single preferred-size individual collected during spring sampling. An ANOVA of relative weights across vegetation categories, season and interactions of category and season showed no significant differences (P>.05) for largemouth bass (Table 5). Similar results were observed for ANCOVA analyses of Wr as an effect of stem density and stand diameter

(Table 5). It should be noted only one individual was observed from the bare substrate category reaching the required minimum total length.

Table 5. Largemouth bass ANOVA and ANCOVA relative weight P-values.

ANOVA	
Source	**P-Value**
Season	0.051
Category	0.518
Category and Season	0.145
ANCOVA	
Season	0.672
Stem Density	0.078
Season and Stem Density	0.079

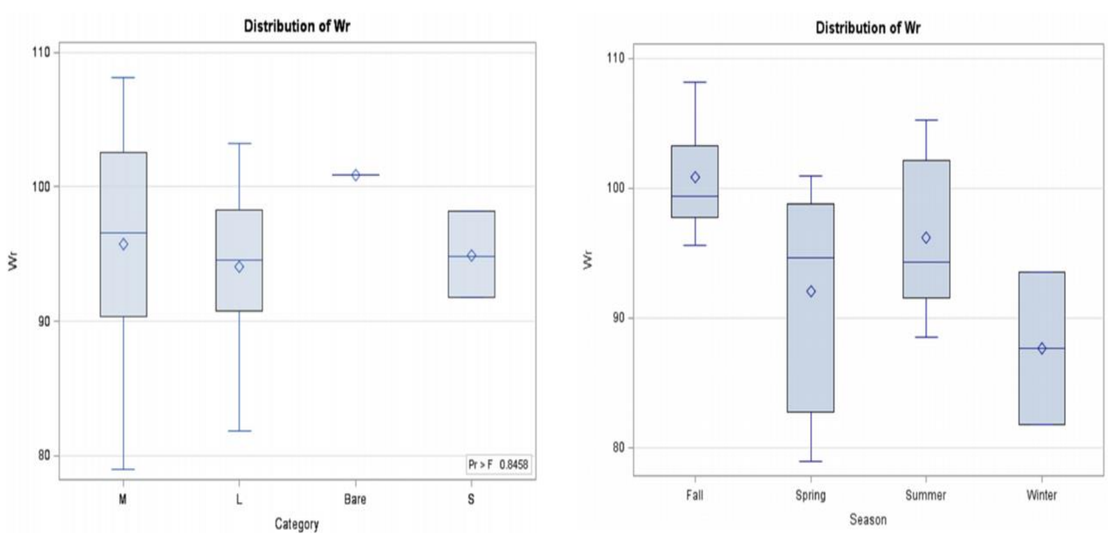

Figure 25 Largemouth bass Wr distribution across category (A) and season (B).

Bluegill Sunfish

Relative weights were calculated for 98 individuals that met minimum total length requirement (Anderson and Neumann, 1966). Bluegill of stock size (N=73) had Wr>90 with the exception of eight individuals; two of those eight were collected during the fall season and the remaining six were collected in the summer (Figure 26). Quality sized bluegill (N=13) showed Wr>90 with the exception of one individual collected in the fall and one individual in the summer sample. An ANOVA of relative weights across vegetation categories, season and their interaction showed no significance (P>0.05, Table 6). Similar ANCOVA results between relative weight, diameter and stem density were observed with no significance (P>0.05, Table 6). No bluegill reaching the minimum total length to calculate Wr were observed from sites in the bare substrate category.

Table 6. Bluegill sunfish ANOVA and ANCOVA relative weight P-values.

ANOVA	
Source	**P-Value**
Season	0.451
Category	0.185
Category and Season	0.539
ACOVA	
Season	0.543
Stem Density	0.123
Season and Stem Density	0.209

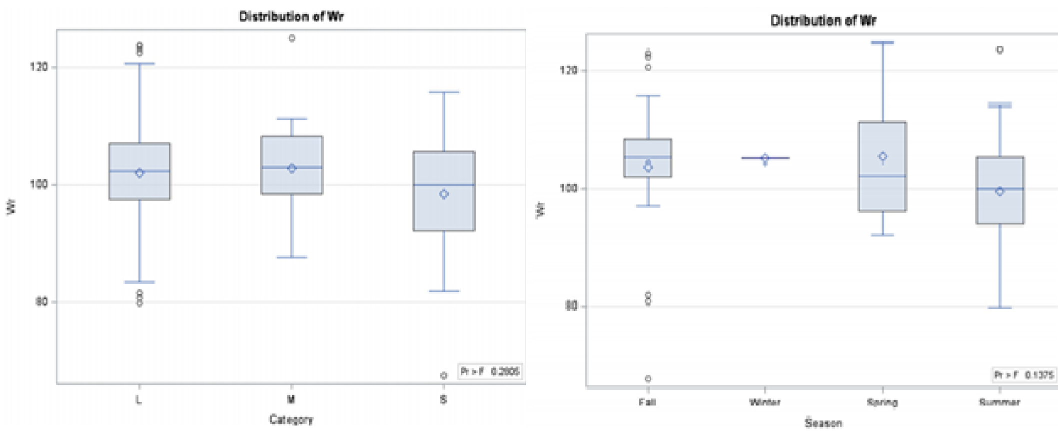

Figure 26 Bluegill Wr distributions across category (A) and season (B).

Channel Catfish

Channel catfish were only observed in the spring sample (N=4). These were collected from medium and large category stands and no significant difference (P>.05) was detected between category or season and their interaction in ANOVA analyses. ANCOVA results were similar with no significant effect of stem density or stand diameter and their interaction.

Fish Assemblage and Multivariate Analysis

A total of 22 fish species were observed, within 14 families across all sites and seasons. The most abundant species were weed shiners (N=1121) and bluegill sunfish (N=1064). Those species excluded that made up <0.1% of fishes observed included common carp (N=3) (*Cyprinus carpio*), bowfin (N=2) (*Amia calva*), freshwater drum (N=2) (*Aplodinotus grunniens*), green sunfish (N=1) (*Lepomis cyanellus*), spotted gar

(N=1) (*Lepisosteus oculatus*), striped bass (N=1) (*Morone chrysops*) and white crappie (N=1) (*Pomoxis annularis*) (Table 7). Percentage is of all individuals collected.

Table 7. Common and uncommon observed fish taxa.

Common			
	Taxa	**N**	**Percentage**
	Weed shiner	1121	28.459
	Bluegill sunfish	1064	27.011
	Threadfin shad	781	19.827
	Inland silverside	462	11.728
	Bullhead minnow	299	7.59
	Largemouth bass	120	2.97
	Brook silverside	16	0.406
	Gizzard shad	15	0.380
	Blacktail shiner	13	0.330
	Redear sunfish	11	0.279
	Bigscale logperch	9	0.228
	Mosquito fish	7	0.126
	Longear sunfish	5	0.126
	Channel catfish	4	0.101
	Orange spotted sunfish	4	0.101
Uncommon			
	Taxa	**N**	**Percentage**
	Common carp	3	0.076
	Bowfin	2	0.050
	Freshwater drum	2	0.050
	Green sunfish	1	0.025
	Spotted gar	1	0.025
	Striped bass	1	0.025
	White crappie	1	0.025

An RDA of common fishes and explanatory variables provided the greatest explained variation (64.4%). An RDA biplot depicts the correlation of fish abundances with explanatory variables (Figure 27 and 28). For this analysis group A (season), B (stem counts and weights) and C (category and diameter m) are observed. The variation partitioning indicated groups for season, size category, stem count and weight and stand diameter were significant ($P<.05$, Table 9). Percent variation explained was highest for E (combined groups B and C) and D (combination of groups A and B) at 28.6% and 21.7% respectively (Table 8). The first axis explained the larger portion of variation amongst groups (Axis 1 explained variation= 48.26%, pseudo-F value=35.6, P-value=0.002). Largemouth bass and weed shiner were correlated with large category stands and also larger stand diameter. Bluegill, bullhead minnow and threadfin shad abundances were correlated with larger steam weights and higher stem density. Other species showed weaker correlations; all abundant fish species were negatively correlated with winter and bare substrate categories. The biplot was restricted to show the five best fitting species, defined as those having %55 variation explained (Figure 28).

Table 8. Variation explained of partitioning RDA analysis of fish assemblage. A=Season, B= Stem Count and Stem Weight and C= Plot Size Category and Diameter. Other letters indicated shared variation among groups as in Figure 3.

Fraction	Variation(adj)	% of Explained	% of All	DF	Mean Square
a	0.076548	13.7	7.7	3	0.03163
b	0.034341	6.1	3.4	2	0.02399
c	0.1141	20.4	11.4	4	0.03486
d	0.12137	21.7	12.1	--	--
e	0.15993	28.6	16.0	--	--
f	0.038313	6.8	3.8	--	--
g	0.01486	2.7	1.5	--	--
Total Explained	0.55947	100.0	55.9	9	0.07154
All Variation	1	--	100	47	--

Table 9. Fraction F and P-values of partitioned RDA analysis of fish assemblage. A=Season, B= Stem Count and Stem Weight and C= Plot Size Category and Diameter; other letters indicate shared variance between groups as shown in Figure 3.

Tested Fraction	F	P
a+b+c+d+e+f+g	7.6	0.002
a	3.4	0.002
b	2.6	0.006
c	3.7	0.002
a+d	7.0	0.002
b+e	8.7	0.002
c+f	4.3	0.002

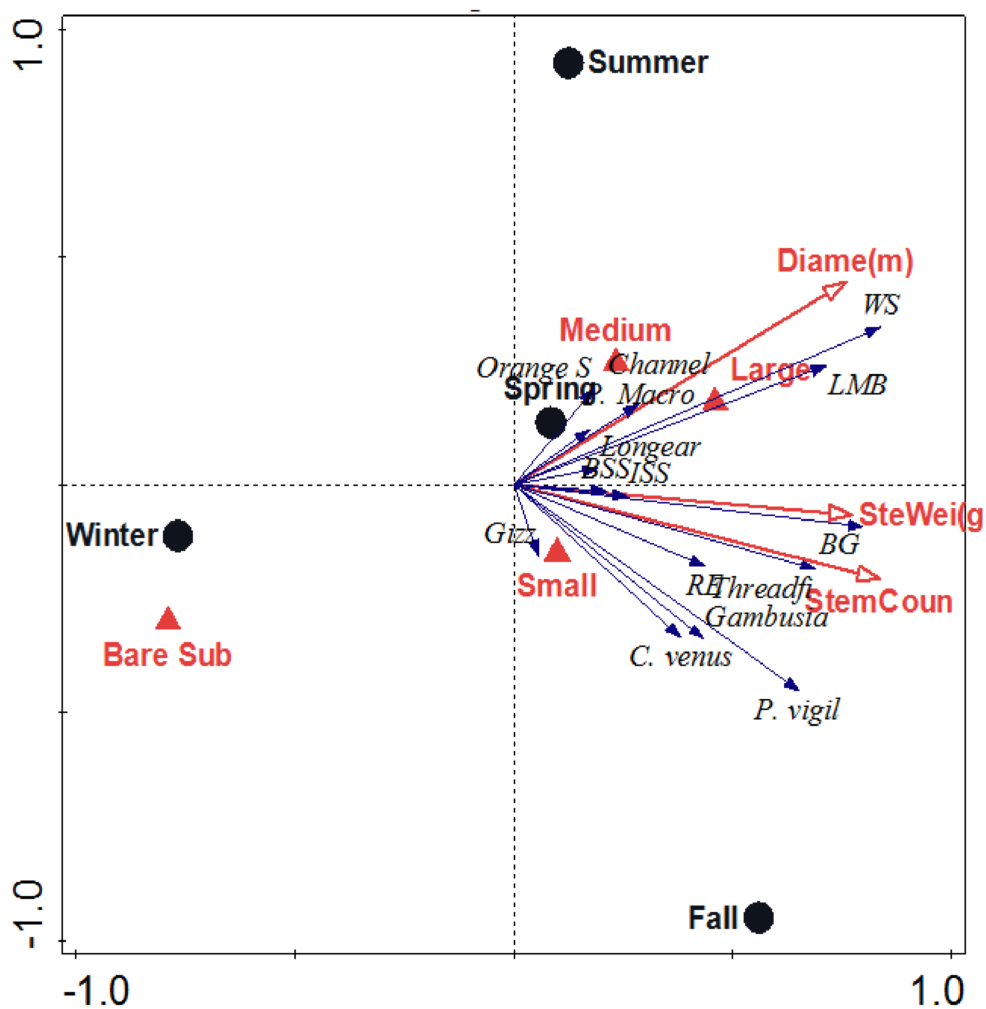

Figure 27 RDA analysis of fish assemblages on 1st and 2nd axes between seasons, category, diameter (m), stem weight and stem count of all common fishes and their vectors.

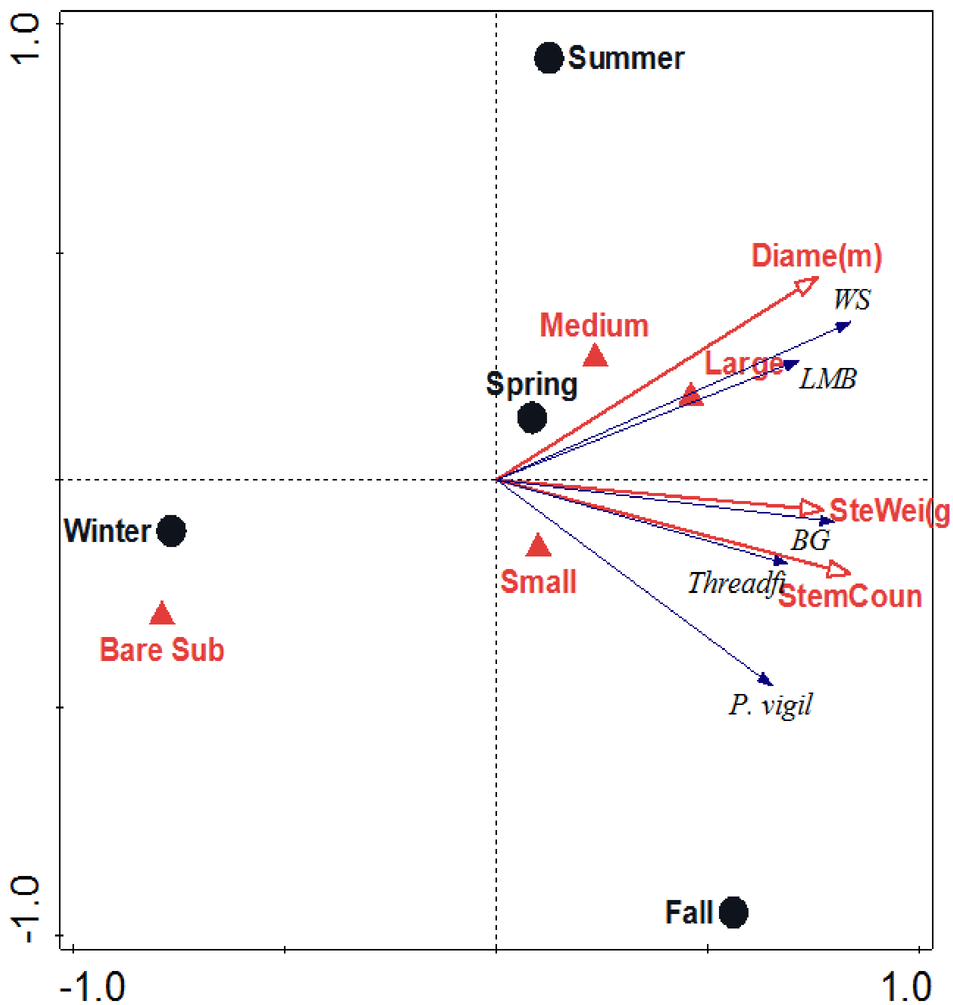

Figure 28 . RDA analysis of fish assemblages on 1st and 2nd axes between seasons, category, diameter (m), stem weight and stem count of the five best (50% variation explained on both axes) fishes and their vectors.

Macroinvertebrate Assemblage and Multivariate Analysis

A total of 37 macroinvertebrate taxa were observed, within 17 orders across all sites and seasons. A total of 14 taxa described as common (made up > 4%) included chironomids which made up 60%; those that were uncommon (made up <0.04%) included 23 taxa often with N=1 (Table 10). An RDA explained 52.5% of the total variation in taxa distribution and was used for a variation partitioning analysis of group A (season and water column location), B (stem counts and stem weight) and C (size category and diameter). Axis 1 explained the most variation and was significant (41.11% of total variation, pseudo-F value= 92.2, P-value=0.002).

A biplot of the first two axes of the RDA was generated to depict the relationships of macroinvertebrate abundances and explanatory variables (Figure 28 A). To make the plot simpler, the five best fitting taxa (defined as 25% variation explained) were plotted (Figure 29). The variation partitioning indicated all groups (season, stand size category, stem density, stem weight, stand diameter and water column location were significant (P<0.05, Table 12). Group A provided the largest explained variation (52.2%, Table10). *Palaemonetes* shrimp were correlated with the fall season. *Amphipoda* were correlated with higher stem count densities, stem weights (g) and the medium size category of stands. *Zygoptera* were correlated with large size category of stands. *Trichoptera* and chironomids were correlated with greater stand diameters and location in the water column.

Table 10. Common and uncommon macroinvertebrate taxa observed. Percentages are of all individuals collected.

	Taxa	Location	N	Percentage
Common Taxa				
	Taxa	**Location**	**N**	**Percentage**
	Chironomidae	Column, Stem, Benthos	24564	60.037
	Amphipoda	Column, Stem, Benthos	11349	27.739
	Trichoptera	Column, Stem, Benthos	3596	8.788
	Gastropoda	Column, Stem, Benthos	585	1.431
	Zygoptera	Column, Stem	312	0.764
	Tetragnathidae	Column, Stem	110	0.268
	Palaemonetes	Column, Stem	102	0.249
	Annelida	Column, Benthos	79	0.193
	Gyrinidae	Stem	51	0.124
	Belostomatidae	Column, Stem	40	0.097
	Naucoridae	Column, Stem	40	0.097
	Hirudinea	Column, Benthos	38	0.092
	Ephemeroptera	Column, Stem, Benthos	27	0.067
	Cordulidae	Column	18	0.046
Uncommon Taxa				
	Taxa	**Location**	**N**	**Percentage**
	Vellidae	Column	4	0.009
	Arachnid	Column, Stem	4	0.009
	Nepidae	Column, Stem	3	0.007
	Pyralidae	Column, Stem	3	0.007
	Dolomedes	Stem	3	0.007
	Corixidae	Column	3	0.007
	Hydrophilidae	Stem, Benthos	3	0.007
	Ceratopogonidae	Benthos	3	0.007
	Bivalvia	Benthos	2	0.004
	Diptera	Column	2	0.004
	Orthoptera	Column	2	0.004
	Argulus	Column	2	0.004
	Chrysomelidae	Benthos	1	0.002
	Heteroceridae	Benthos	1	0.002
	Cicadellidae	Column	1	0.002
	Gerridae	Column	1	0.002
	Grillidae	Stem	1	0.002
	Coccinellidae	Stem	1	0.002
	Libullelidae	Stem	1	0.002
	Ptychopteridae	Benthos	1	0.002
	Gomphidae	Benthos	1	0.002
	Decapoda	Column	1	0.002
	Eulophidae	Benthos	1	0.002

Table 11. RDA variation partitioning analysis of macroinvertebrate assemblage. A=Season, B= Stem Count and Stem Weight and C= Plot Size Category and Diameter; other letters indicate shared variation among groups as indicated in Figure 3.

Fraction	Variation(adj)	% of Explained	% of All	DF	Mean Square
a	0.2556	52.2	25.6	5	0.05254
b	0.026335	5.4	2.6	2	0.01591
c	0.070563	14.4	7.1	4	0.02035
d	0.016391	3.3	1.6	--	--
e	0.13709	28.0	13.7	--	--
f	0.012288	2.5	1.2	--	--
g	-0.028614	-5.8	-2.9	--	--
Total Explained	0.48964	100.0	49.0	11	0.04808
All Variation	1	--	100.0	143	--

Table 12. Fraction F and P-values of macroinvertebrate assemblage RDA variation partitioning. A=Season and Water Column Location, B= Stem Count and Stem Weight and C= Category and Diameter; other letters indicate shared variation among groups as indicated in Figure 3.

Tested Fraction	F	P
a+b+c+d+e+f+g	13.5	0.002
a	14.7	0.002
b	4.5	0.002
c	5.7	0.002
a+d	15.1	0.002
b+e	20.4	0.002
c+f	4.8	0.002

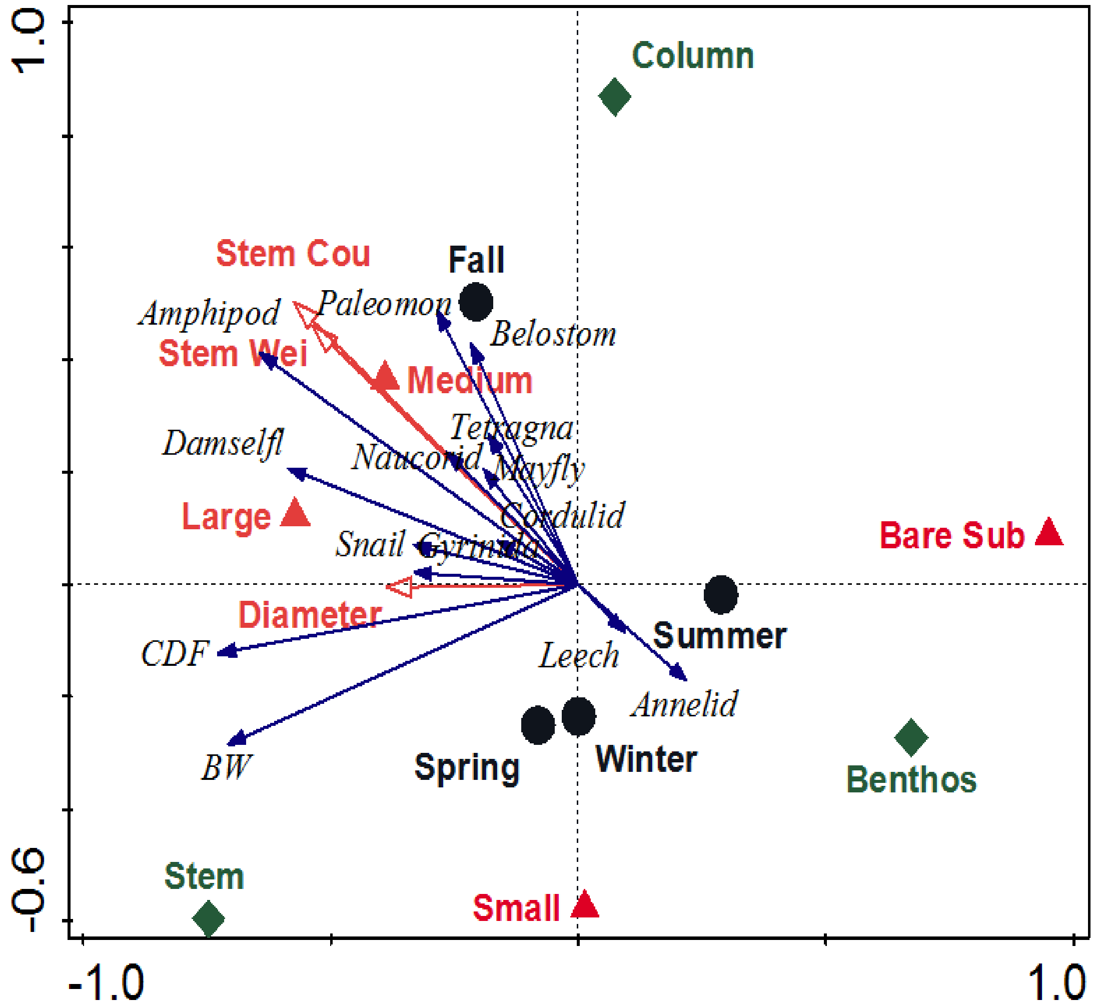

Figure 29 RDA analysis of macroinvertebrate assemblages on 1st and 2nd axes between seasons, category diameter (m), stem weight, stem count and macroinvertebrate location of all common macroinvertebrates.

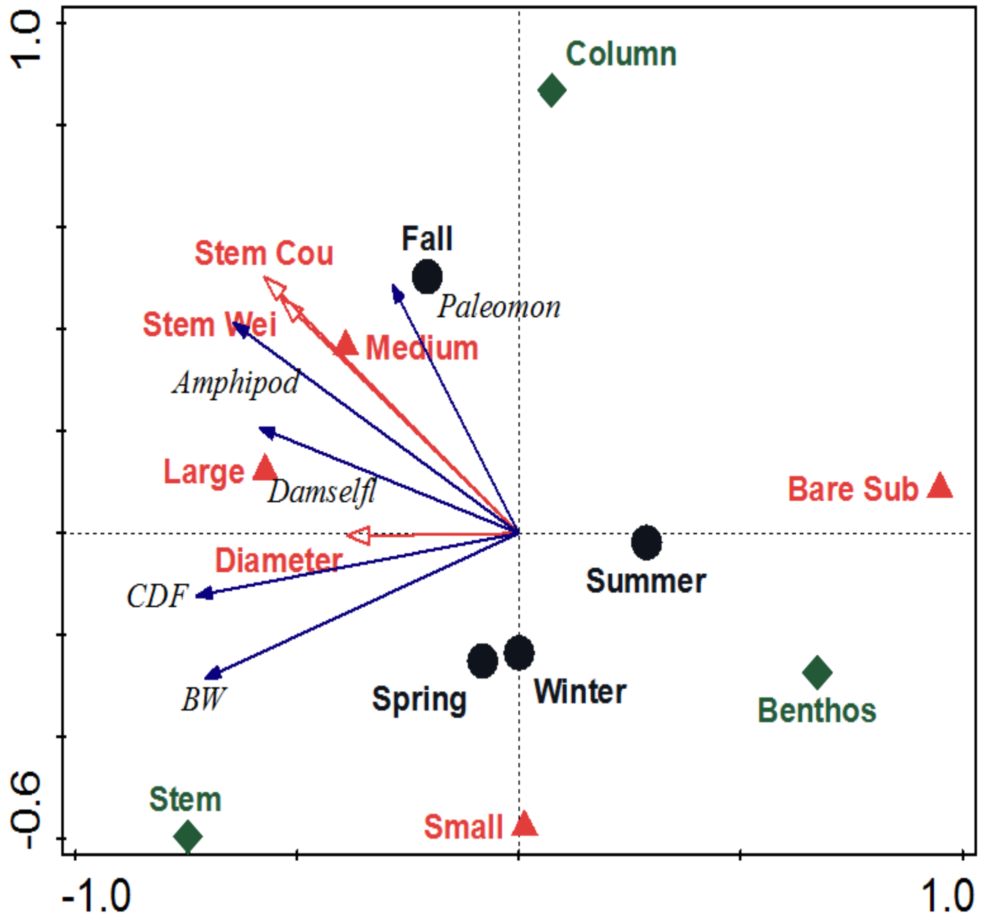

Figure 30 RDA analysis of macroinvertebrate assemblages on 1st and 2nd axes between season, category diameter (m), stem weight, stem count and macroinvertebrate location of the 5 best fit (25% variation explained on both axes) macroinvertebrates and their vectors.

Stable Isotope

Fishes collected for isotopic analysis consisted of ten individuals per species, except that only seven bigscale logperch were collected for analysis. Isotopic signatures showed that plankton, periphyton and water willow were basal primary producers and all of the consumers except chironomids, had higher nitrogen signatures (Figure 29). No consumers had Carbon signatures near those of water willow, indicating plankton and periphyton were likely the main basal producers incorporated into the higher trophic levels.

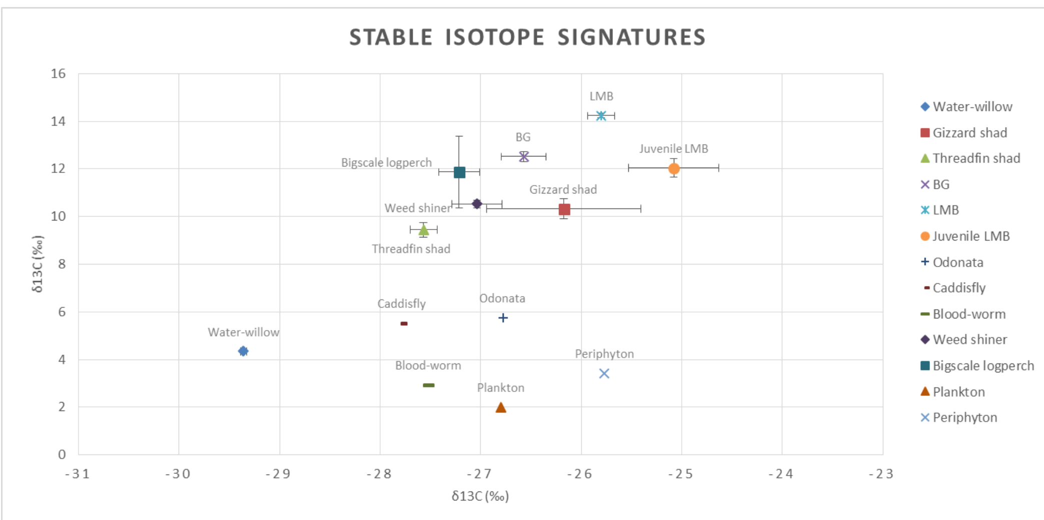

Figure 31 Stable isotope signature (means ± S.E.) of fishes, water-willow, periphyton, plankton and macroinvertebrates. Note: Periphyton, plankton and macroinvertebrate samples are homogenized of multiple individuals and therefore do not have S.E. bars.

CHAPTER IV

DISCUSSION AND CONCLUSIONS

Fish Assemblage

Univariate analyses indicated no significant difference in assemblage structure between water-willow stand size categories, suggesting that stand size had little effect on fish species abundances. The same can be said for effects of water-willow stand size on water parameters and on relative weights for largemouth bass, bluegill and channel catfish.

Fish assemblages showed a positive correlation with vegetated stands and negative correlation with bare substrate. Fishes in Lake Conroe utilize water-willow increasingly as stand size and stem density increased, similar to findings of other studies in streams and experimental manipulations (Rennie et al., 2005; Savino et al., 1992; Spotte, 2007; Beckett et al., 1992, Killgore et al., 1993). Previous studies have stated that varying structural complexity does affect forage efficiency, where individual prey capture rates was higher amongst simple stem structure of bulrush (*Scirpus validus*) opposed to branched structure of pondweed (*Potamogeton amplifolius*) (Spotte, 2007).

Larger largemouth bass (> 15 cm) captured in vegetated study sites may use vegetation to hunt for prey that are seeking cover. Nest spawning fishes prefer to construct beds in closer proximity to vegetation for refuge (Annett et al. 1996) but this was not observed in this study. Additionally, abundances of smaller-bodied prey fishes such as *Lepomis sp.*, *Cyprinids* and threadfin shad were correlated with increased water-willow stem densities. These potential prey fishes commonly utilize vegetation as cover (Ross, 2001). More specifically both largemouth bass and weed shiners were strongly correlated with large-size stands. Ross et al. (2001) describe the weed shiner habitat preference in reservoirs as shallow, weedy coves. Water-willow, in the absence of other vegetation, can serve as a weedy habitat. Although the weed shiner utilizes water-willow as a resource, largemouth bass can potentially take advantage of this prey species by inhabiting water-willow stands, or surrounding areas while hunting. Vegetated stands also provided an increased taxa count, which for predatory fishes such as largemouth bass and bluegill sunfish, increases prey variety. This variety allows species to feed on preferred prey items and sizes as fish grow larger (Spotte, 2007).

Fish species appeared to be weakly correlated with season, except for channel catfish and orange spotted sunfish. Channel catfish were only found during the spring season during my study. Their seasonal collection may be related to their upstream and shoreward migration observed in other studies of lentic and lotic populations (Duncan and Myers 1978; Dames et al. 1989). However, their low abundance in my study limits the inference for their relationship with water-willow stands.

Macroinvertebrate Assemblage

The common macroinvertebrate taxa were most abundant in vegetated versus bare substrate category, as observed for fishes. Macroinvertebrates were most abundant in collections from stems (N=34,096), and the water column and stem location samples held the most taxa (N=12 and N=11, respectively). Thus macroinvertebrates, like fishes, may be utilizing water-willow as habitat (Rennie et al., 2005; Savino et al., 1992; Spotte, 2007; Beckett et al., 1992). Leeches and annelids were the sole taxa present in the benthos samples, with annelids showing the stronger correlation (Figure 28). This agrees with their ecological association as benthic taxa (De Lange, 1994).

Chironomids were the most abundant macroinvertebrate taxa observed and were found in all water column samples. This is likely related to chironomids being the most abundant macroinvertebrate taxon in freshwater systems (Armitage, et al., 1995; Epler, 1995; Tokeshi, 1995[a]). Their high abundance and correlation with vegetated stands suggests they utilize water-willow more than bare substrate in Lake Conroe.

Amphipoda were correlated with increased stem weights and stem counts. Their presence in high stem density sites may be due to the increased surface area for attachment and their utilization of epiphytes as a food source (Hargrave, 1970). *Palaemonetes* shrimp showed correlation with the fall season and medium category stands. *Palaemonetes* likely utilize water-willow as an attachment point to feed on epiphytes (Morgan 1980; Quińones-Rivera and Fleeger 2005; McCall and Rakocinski 2007). *Palaemonetes* typically aggregate and exhibit patchy distribution (Eggleston et al. 1998). Similarly, *Zygoptera* larvae were associated with large category sites (Figure 28 and 29). These large stands provide the cover from predators that is required to complete their lifecycle and later emerge as adults (Cowx and Welcomme 1998).

Fish Stomach Contents

The finding of no effect of water-willow on relative weights, is likely related to the ability of larger individuals to move throughout the water body, allowing utilization of multiple sites and resources. For example, Largemouth bass have been documented in a mark recapture study to move as far as 14km from their original capture site (Taylor et al. 2015). Largemouth bass also were relocated according to season, occupying shallow waters during the summer months and deeper waters during winter (Demers et al. 1996; Karchesky and Bennett 2004). This movement and utilization of other resources may explain no effect of water-willow on relative weight ($P>0.05$). Previous bluegill sunfish studies have observed no difference in growth rates when fish were exposed to multiple vegetation densities (Savino et al., 1992; Beckett et al., 1992), which suggests that water-willow stem density would not significantly impact relative weights.

Smaller largemouth bass (< 15 cm) made up the majority of individuals, which suggests that water-willow may act as nursery habitat by providing protection from predators and habitat structure inhabited by prey taxa consumed by juveniles. Similar observations of bluegill sunfish suggest they also utilize water-willow in a similar manner. Association of juvenile fishes with macrophytes and higher vegetation density has been suggested in previous studies (Barnett and Schneider 1974; Moxley and Langford 1982). Evidence for prey habitat use in water willow is supported by the positive correlation between macroinvertebrate count data and vegetated sites, and higher occurrence of chironomids in stomach contents for both largemouth bass and bluegill sunfish. Macrophytes are known to hold concentrations of both high diversity and abundance of prey fish and prey macroinvertebrate taxa (Moxley and Langford 1982). A study observing bluegill sunfish stomach contents provided similar conclusions, stating the majority of stomach contents of bluegill sunfish contained epiphytic macroinvertebrates (Spotte, 2007).

The high presence of chironomids in *Cyprinid* stomachs, and correlation of *Cyprinid* fishes and chironomid abundance in vegetated sites and support the use of water-willow by *Cyprinid* fishes as a foraging habitat. A study by Tokeshi (1995[b]) shows that chironomids are often selected as prey by invertivores. Weed shiner in particular have been noted to scrape detritus from macrophyte leaves, and when prey are abundant, diets become more broad to include macroinvertebrate prey from various water column locations (Simon, 1999; Felley and Felley, 1987). The bullhead minnow and black tail shiner include macroinvertebrates in the diet more continuously than do weed shiners (Simon, 1999; Goldstein and Simon, 1999). It should be noted, *Cyprinid* stomach contents often relied on counting sclerotized head capsules of chironomid larvae. This is presumed to be due to their pharyngeal teeth that crush prey prior to digestion. Bluegill sunfish also utilize insect larvae as a key prey item, including chironomid larvae (Spotte, 2007), which were the most abundant macroinvertebrate taxa (N=24,564) in this Lake Conroe study.

Stable Isotope Analysis

Plankton and periphyton C signatures indicate they are the primary basal taxa of these littoral zone food webs. Periphyton was attached to the water-willow stems thus, indirectly water-willow is contributing to the food chain by providing additional attachment surface area for periphyton. This periphyton is a presumed food source for chironomids and other macroinvertebrates which become prey for fishes in higher trophic levels, as seen in the stomach content data. As water-willow spreads it has the ability to increase surface area for periphyton attachment. This increases potential food resources for species in higher trophic levels meanwhile supporting increased biodiversity within water-willow patches in reservoirs.

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